THE PROCEEDINGS OF THE PHYSICAL SOCIETY

VOL. 53, PART 1 — 1 January 1941 — No. 295

CONTENTS

Price to non-Fellows 7*s.* net; post free 7*s.* 5*d.*
Annual subscription 35*s.* post free, payable in advance

Published by

THE PHYSICAL SOCIETY
1 Lowther Gardens, Exhibition Road
London, S.W. 7

Printed by

TAYLOR AND FRANCIS, LTD.,
RED LION COURT, FLEET STREET, LONDON, E.C. 4

THE PHYSICAL SOCIETY

FOUNDED 1874 . INCORPORATED 1878

OFFICERS OF THE SOCIETY, 1940–41:

President:—ALLAN FERGUSON, M.A., D.Sc.

Hon. Secretaries:—

W. JEVONS, D.Sc., Ph.D. (*Business*).

J. H. AWBERY, B.A., B.Sc. (*Papers*).

Hon. Foreign Secretary:—Sir OWEN W. RICHARDSON, M.A., D.Sc., F.R.S.

Hon. Treasurer:—C. C. PATERSON, O.B.E., D.Sc., M.I.E.E.

Hon. Librarian:—J. H. BRINKWORTH, D.Sc., A.R.C.S.

Assistant Secretary (Acting):—Mrs. D. M. G. CARRINGTON, B.Sc.

Office of the Society:—1 *Lowther Gardens, Exhibition Road, London, S.W.7.*
Telephone: *Kensington* 0048.

INSTRUCTIONS TO AUTHORS

NOTE. The acceptance of a paper for publication in the Proceedings rests with the Council, advised by its Editing Committee. The high cost of printing renders it imperative to exclude matter that is not novel and not of importance to the understanding of the paper.

Authors offering original contributions for publication in the Proceedings should observe the following directions; failure to comply with these may cause considerable delay in publication.

Manuscript.—A clear and concise style should be adopted, and the utmost brevity consistent with effective presentation of the original subject-matter should be used. The copy should be easily legible, preferably typewritten and double-spaced. It should receive a careful final revision before communication, since alterations are costly when once the type has been set up. Mathematical expressions should be set out clearly, in the simplest possible notation.

References.—In references to published papers the author's name and initials followed by the year and then by the title of the journal in italics, volume and page should be given thus: Vincent, J. H., 1931. *Proc. Phys. Soc.* 43, 157. The abbreviations given in the *World List of Scientific Periodicals* should be employed.

Drawings and tables.—Diagrams must be carefully drawn in Indian ink on white paper or card. Their size and thickness of line must be sufficient to allow of reduction. *Lettering and numbering should be in pencil,* to allow of printing in a uniform style. The number of diagrams should be kept down to the minimum. Photographs of apparatus are not ordinarily accepted. Data should in general be presented in the form of either curves or tables, but not both. Footlines descriptive of figures, and headlines indicative of contents of tables, should be supplied. *Sheets should not be larger than foolscap.*

Abstracts.—Every paper must be accompanied by an abstract in duplicate, brief but sufficient to indicate the scope of the paper and to summarize all novel results.

Proofs.—Proofs of accepted papers will be forwarded to authors. They should be returned promptly with errors corrected, but additions to or other deviations from the original copy should be avoided. When the cost of alterations to proofs, apart from corrections of errors, exceeds 5 per cent of the cost of setting up the type of the paper, the excess must be borne by the author.

Reprints.—Fifty copies of printed papers will be supplied gratis. Extra copies may be purchased at cost price.

Contributions by non-Fellows.—Papers by non-Fellows must be communicated to the Society through a Fellow.

Republication.—Permission to reproduce papers or illustrations contained therein may be granted by the Council on application to the Hon. Secretaries.

INDEX SLIP

OF THE

PROCEEDINGS OF THE PHYSICAL SOCIETY

Vol. 52, 1940, Part 6

SUBJECT INDEX

532.13

Andrade, E N da C
1940.06.08. The viscosity of liquids.
Proc. phys. Soc. Lond. **52,** 748–758 (1940).

532.61

Ferguson, Allan
1940.08.09. Relations between thermo-physical properties.
Proc. phys. Soc. Lond. **52,** 759–763 (1940).

535.421 : 541.18.041.2

Tilleard, Dorothy L
1940.03.08. Controlled flocculation.
Proc. phys. Soc. Lond. **52,** 828 (1940).

536.632 : 547.222.1

Awbery, J H
Griffiths, Ezer
1940.07.24. The specific heat of liquid methyl chloride.
Proc. phys. Soc. Lond. **52,** 770–776 (1940).

536.75

Lennard-Jones, J E
1940.08.03. The liquid state.
Proc. phys. Soc. Lond. **52,** 729–747 (1940).

537.226 : 539.32 : 679.56

Hartshorn, L
Megson, N J L
Rushton, E
1940.08.13. Molecular relaxation and the elastic and dielectric properties of plastics.
Proc. phys. Soc. Lond. **52,** 817–821 (1940).

537.226 : 679.56

Hartshorn, L
Megson, N J L
Rushton, E
1940.08.13. The dielectric properties of some thermoplastics.
Proc. phys. Soc. Lond. **52,** 796–816 (1940).

537.523.4

Meek, J M
1940.09.11. The variation of sparking potential with initial photo-electric current: Part II.
Proc. phys. Soc. Lond. **52,** 822–827 (1940).

537.533.73

Haque, A
1940.06.21. A study of the background in electron-diffraction patterns.
Proc. phys. Soc. Lond. **52,** 777–795 (1940).

539.32 : 679.56 : 537.226

Hartshorn, L
Megson, N J L
Rushton, E
1940.08.13. Molecular relaxation and the elastic and dielectric properties of plastics.
Proc. phys. Soc. Lond. **52,** 817–821 (1940).

541.12–14

Corner, J
1940.04.29. The distribution function of a simple liquid model.
Proc. phys. Soc. Lond. **52,** 764–767 (1940).

541.12–14

Fürth, R
1940.04.29. On the theory of holes in liquids.
Proc. phys. Soc. Lond. **52,** 768–769 (1940).

541.12–14

Lennard-Jones, J E
1940.08.03. The liquid state.
Proc. phys. Soc. Lond. **52,** 729–747 (1940).

541.18.041.2 : 535.421

Tilleard, Dorothy L
1940.03.08. Controlled flocculation.
Proc. phys. Soc. Lond. **52,** 828 (1940).

547.222.1 : 536.632

Awbery, J H
Griffiths, Ezer
1940.07.24. The specific heat of liquid methyl chloride.
Proc. phys. Soc. Lond. **52,** 770–776 (1940).

679.56 : 537.226

Hartshorn, L
Megson, N J L
Rushton, E
1940.08.13. The dielectric properties of some thermoplastics.
Proc. phys. Soc. Lond. **52,** 796–816 (1940).

679.56 : 537.226 : 539.32

Hartshorn, L
Megson, N J L
Rushton, E

1940.08.13. Molecular relaxation and the elastic and dielectric properties of plastics.
Proc. phys. Soc. Lond. **52,** 817–821 (1940).

92 (Crompton, R E B)

Appleyard, Rollo

1940.11.01. Rookes Evelyn Bell Crompton.
Proc. phys. Soc. Lond. **52,** 829–830 (1940).

AUTHOR INDEX

532.13

Andrade, E N da C

1940.06.08. The viscosity of liquids.
Proc. phys. Soc. Lond. **52,** 748–758 (1940).

92 (Crompton, R E B)

Appleyard, Rollo

1940.11.01. Rooks Evelyn Bell Crompton.
Proc. phys. Soc. Lond. **52,** 829–830 (1940).

547.222.1 : 536.632

Awbery, J H
Griffiths, Ezer

1940.07.24. The specific heat of liquid methyl chloride.
Proc. phys. Soc. Lond. **52,** 770–776 (1940).

541.12–14

Corner, J

1940.04.29. The distribution function of a simple liquid model.
Proc. phys. Soc. Lond. **52,** 764–767 (1940).

532.61

Ferguson, Allan

1940.08.09. Relations between thermo-physical properties.
Proc. phys. Soc. Lond. **52,** 759–763 (1940).

541.1 2–14

Fürth, R

1940.04.29. On the theory of holes in liquids.
Proc. phys. Soc. Lond. **52,** 768–769 (1940).

547.222.1 : 536.632

Griffiths, Ezer
Awbery, J H

1940.07.24. The specific heat of liquid methyl chloride.
Proc. phys. Soc. Lond. **52,** 770–776 (1940).

537.533.73

Haque, A

1940.06.21. A study of the background in electron-diffraction patterns.
Proc. phys. Soc. Lond. **52,** 777–795 (1940).

Digitized by the Internet Archive
in 2024

https://archive.org/details/proceedings-of-the-physical-society_1941-01-01_53_part-1

679.56 : 537.226

Hartshorn, L
Megson, N J L
Rushton, E

1940.08.13. The dielectric properties of some thermoplastics.
Proc. phys. Soc. Lond. **52,** 796–816 (1940).

679.56 : 537.226 : 539.32

Hartshorn, L
Megson, N J L
Rushton, E

1940.08.13. Molecular relaxation and the elastic and dielectric properties of plastics.
Proc. phys. Soc. Lond. **52,** 817–821 (1940).

541.12–14

Lennard-Jones, J E

1940.08.03. The liquid state.
Proc. phys. Soc. Lond. **52,** 729–747 (1940).

537.523.4

Meek, J M

1940.09.11. The variation of sparking potential with initial photo-electric current : Part II.
Proc. phys. Soc. Lond. **52,** 822–827 (1940).

679.56 : 537.226

Megson, N J L
Rushton, E
Hartshorn, L

1940.08.13. The dielectric properties of some thermoplastics.
Proc. phys. Soc. Lond. **52,** 796–816 (1940).

679.56 : 537.226 : 539.32

Megson, N J L
Rushton, E
Hartshorn, L

1940.08.13. Molecular relaxation and the elastic and dielectric properties of plastics.
Proc. phys. Soc. Lond. **52,** 817–821 (1940).

679.56 : 537.226

Rushton, E
Hartshorn, L
Megson, N J L

1940.08.13. The dielectric properties of some thermoplastics.
Proc. phys. Soc. Lond. **52,** 796–816 (1940).

679.56 : 537.226 : 539.32

Rushton, E
Hartshorn, L
Megson, N J L

1940.08.13. Molecular relaxation and the elastic and dielectric properties of plastics.
Proc. phys. Soc. Lond. **52,** 817–821 (1940).

541.18.041.2 : 535.421

Tilleard, Dorothy L

1940.03.08. Controlled flocculation.
Proc. phys. Soc. Lond. **52,** 828 (1940).

ADVERTISEMENTS

IN THE

PROCEEDINGS

Rates for one insertion—

	£	s.	d.
Page	5	0	0
Half-page	3	0	0
Quarter-page	1	15	0
Eighth-page	1	0	0

Rates for special positions upon application.

10% and 20% reductions for series of three and of six, respectively, in consecutive issues.

Applications for space should be made to the Honorary Secretary (Business),

THE PHYSICAL SOCIETY
1 LOWTHER GARDENS,
EXHIBITION ROAD, LONDON, S.W. 7
(Telephone: Kensington 0048)

Indicating
Recording
Controlling

ELECTRICAL PYROMETERS

Resistance
Thermoelectric
Radiation
Optical

for high or low temperature ranges

BOWEN INSTRUMENT Co. Ltd.
9 Newton Road, LEEDS, 7.

BALDWIN INSTRUMENT Co. Ltd.

CUMNOR
Nr OXFORD

BESIDES THE USUAL ELECTRICAL MEASURING INSTRUMENTS WE SPECIALISE IN ELECTRONIC DEVICES OF PARTICULAR INTEREST TO THE PHYSICIST, SUCH AS

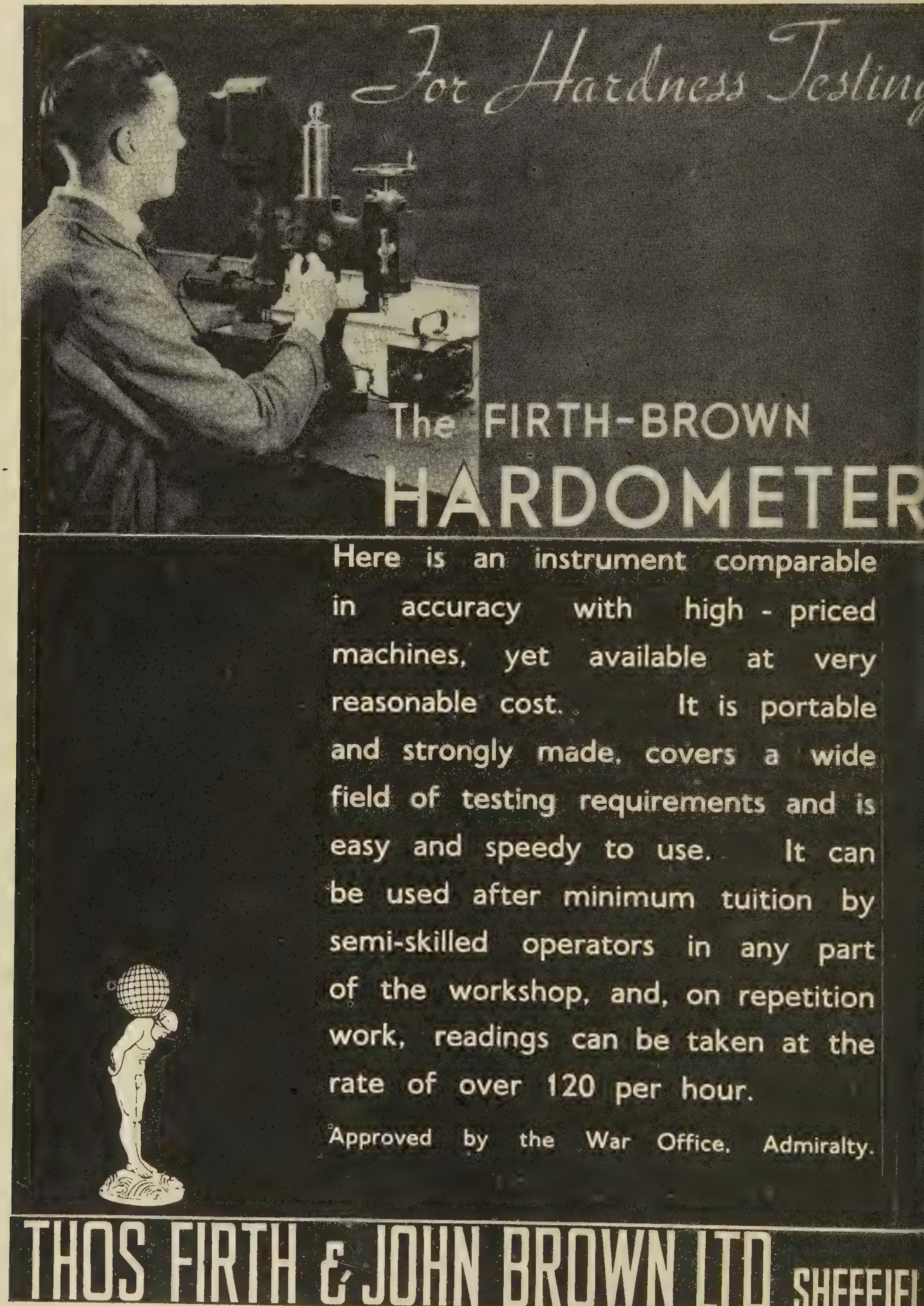
APPARATUS FOR THE MEASUREMENT OF FT.-CANDLE SECONDS,
FOR THE MEASUREMENT OF RÖNTGENS,
FOR THE MEASUREMENT OF EXTRA-HIGH RESISTANCE,

AND ALSO

ELECTRIC TIME DEVICES.

WE WILL BE GLAD TO HAVE YOUR ENQUIRIES.

TELEPHONE: CUMNOR 236, 237.


For Hardness Testing
The FIRTH-BROWN
HARDOMETER
Here is an instrument comparable in accuracy with high - priced machines, yet available at very reasonable cost. It is portable and strongly made, covers a wide field of testing requirements and is easy and speedy to use. It can be used after minimum tuition by semi-skilled operators in any part of the workshop, and, on repetition work, readings can be taken at the rate of over 120 per hour.
Approved by the War Office, Admiralty.
THOS FIRTH & JOHN BROWN LTD SHEFFIEL

SCIENTIFIC BOOKS

Corner of Gower St. and Gower Place
adjoining University College
Telephone: EUSton 4282 (5 lines)

Messrs H. K. LEWIS can supply from stock or to order any book on the Physical and Chemical Sciences. Foreign books not in stock are obtained under Special Licence. Books are sent Cash on Delivery wherever the system operates.

SCIENTIFIC LENDING LIBRARY

Annual subscription from **One Guinea.** The Library is particularly useful to Societies and institutions, and to those engaged on research work. Detailed prospectus post free on application.

READING ROOM FOR SUBSCRIBERS

Bi-monthly List of Additions, free on application

PLEASE WRITE FOR CATALOGUES STATING INTERESTS.

H. K. LEWIS & Co. Ltd.

136 GOWER STREET

LONDON, W.C.1

FOSTER PYROMETERS

Expert advice free

FOSTER INSTRUMENT CO. LTD.

LETCHWORTH, HERTS

'phone: Letchworth 26 & 626 *'grams: "Resilia," Letchworth*

W.T. 38

Wratten METALLOGRAPHIC Plates

In photographic plates for photomicrography, high resolution is often required but adequate working speed is also of importance. Most instruments are designed to give sharpest possible focus in the region of maximum visual sensitivity, and Wratten Metallographic Plates have been specially designed for such work. They possess a very high green and yellow sensitivity. Little speed is therefore lost when working with a yellow filter, and the plates yield the maximum definition attainable with convenient working speed.

Being orthochromatic these plates may be processed in red light (Wratten Series 2). D-19 is the developer recommended for normal use.

PHOTOGRAPHIC PLATES FOR SCIENTIFIC PURPOSES

One aspect of the service provided by the Kodak Research Laboratory is to supply plates for specific scientific purposes ; spectrography, astronomy, infra-red and ultra-violet photography, to name only a few. One example of the range of plates available is the Wratten Metallographic Plate, described above.

Kodak Ltd. are also prepared to make plates to specification for requirements outside the normal range. Enquiries for plates for special work should be addressed to the Kodak Research Laboratory. The booklet "Photographic Plates for Scientific Purposes" will be sent free on request.

PHOTOGRAPHIC GRATICULES

We can undertake the production of photographic GRATICULES by a method which has a resolution figure of at least 600 *lines per millimetre.*

Kodak Ltd. THE RESEARCH LABORATORY, WEALDSTONE, HARROW, MIDDLESEX

'AVO'

Regd. Trade Mark

Electrical Measuring Instruments

BRITISH MADE

MODEL 40 AVOMETER

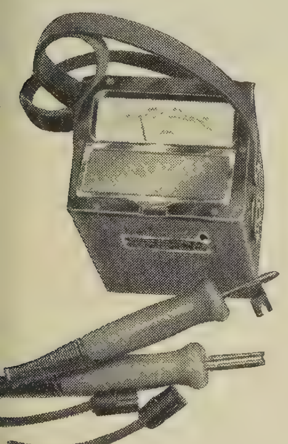
THE MODEL 40 UNIVERSAL AVOMETER

A self-contained combination A.C./D.C. meter providing 40 ranges of *direct* readings as follows :—Current—A.C. 6 mA. to 12 A. (in 8 ranges) and D.C. 6 mA. to 12 A. (in 8 ranges). Voltage—A.C. 6 v. to 1,200 v. (in 8 ranges) and D.C. 60 mv. to 1,200 v. (in 12 ranges). Ohms—0–1 megohm (in 4 ranges), reading down to 0·1 ohm. The instrument conforms to B.S. 1st grade accuracy requirements and is provided with an automatic protective cut-out instead of a replaceable fuse.

THE 'AVO' TEST BRIDGE

A self-contained 50 cycles measuring bridge of exceptional accuracy and utility. Provides for the direct measurement of all normal values of condensers and resistances, and measures capacities from ·000005 mfd. to 50 mfds. in 3 ranges and resistance from 5 ohms to 50 megohms in 3 ranges. Accuracy (except at extremes of ranges) is *better than* 5 *per cent.* Provision for condenser power factor and leakage tests and also for inductance measurements from 0·1 Henry upwards using external standards. May be used as a valve voltmeter indicator for voltage measurement at audio and low radio frequencies.

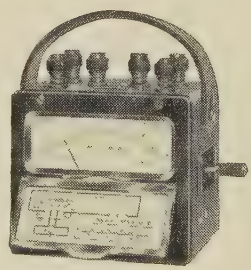
THE 'AVO' TEST BRIDGE



THE 'AVO' BONDING METER

THE 'AVO' BONDING METER

A portable instrument specially developed for bonding tests and similar applications where very low resistance values are involved. Measurements are taken directly on a 4-inch scale uniformly calibrated into 50 divisions with range values from 0–10 milliohms to 0–1 ohm as required. The crossed coil movement employed is substantially independent of testing voltage which is supplied by a 10 A.H. nickel-iron accumulator housed in rear of case. Complete with 3 ft. leads (fitted with plug for meter) and testing handles provided with spikes at outer end.



THE 'AVO' MILLIOHMMETER

THE 'AVO' MILLIOHMMETER. Of somewhat similar design is the series of 'AVO' Milliohmmeters, which are double-range Instruments requiring an external 2-volt accumulator for their operation. These Instruments are available for ranges of measurements which fall between 0–1 milliohm and 0–1 ohm. Full details will be gladly sent on request.

Sole Proprietors and Manufacturers:

THE AUTOMATIC COIL WINDER & ELECTRICAL EQUIPMENT CO. LTD.

WINDER HOUSE, DOUGLAS STREET, LONDON, S.W. 1. *Telephone: VICtoria 3404/7*

ALUMINA INSULATORS

FOR HIGH ELECTRICAL RESISTANCE AT HIGH TEMPERATURES.

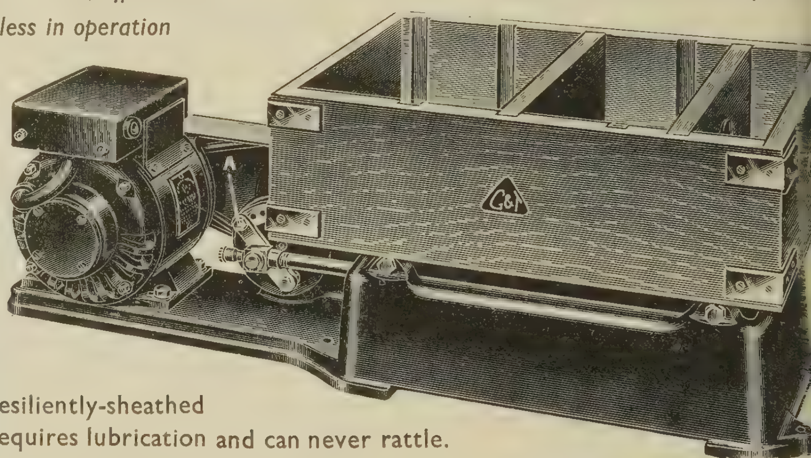
THE THERMAL SYNDICATE LTD.

Head Office & Works : **Wallsend, Northumberland.**
London Depot : **12–14 Old Pye Street, Westminster, S.W. 1**

THE MICROID SILENT SHAKING MACHINI

New modern design, compact in size, efficient in performance and noiseless in operation

Leaflet GT1239 on reques



- *SILENT*
- *EFFICIENT*
- *ROBUST*
- *ADAPTABLE*

- Incorporates a new resiliently-sheathed bearing which never requires lubrication and can never rattle.
- Utilises an unusual ratio $\frac{\text{shaker speed}}{\text{shaker throw}}$ resulting in extraordinarily efficient mixing, shakin washing, extraction, etc.

GRIFFIN and TATLOCK Ltd

LONDON	MANCHESTER	LIVERPOOL	GLASGOW	EDINBURGH
Kemble St., W.C.2.	19 Cheetham Hill Rd., 4.	164 Brownlow Hill, 3.	45 Renfrew St., C.2.	7 Teviot Place, I

WM. DAWSON & SONS, LTD.

RARE BOOK DEPT.

WE WISH TO PURCHASE COMPLETE SETS, RUNS OR ODD VOLUMES OF ALL SCIENTIFIC JOURNALS, BRITISH AND FOREIGN, AND BOOKS ON THE HISTORY OF SCIENCE

HIGHEST PRICES PAID

EST. 1809 | CITY 3761

LONDON

CANNON HOUSE, PILGRIM ST., E.C.4

MACMILLAN

Electrical Contacts

By G. Windred, A.M.I.E.E. 16*s.* net

Theory and Practice of Electron Diffraction

By Prof. G. P. Thomson, F.R.S. and Dr. W. Cochrane. 18*s.* net

X-Rays in Theory and Experiment

By Prof. A. H. Compton and Prof. S. K. Allison. 31*s.* 6*d.* net

Measurement of Inductance, Capacitance and Frequency

By A. Campbell and Dr. E. C. Childs. 30*s.* net

A Text-Book of Heat.

By Prof. H. Stanley Allen, F.R.S. and R. S. Maxwell. Part I. 10*s.*, Part II. 10*s.* 6*d.*

A Text-Book of Light

By G. R. Noakes. 6*s.*

Intermediate Practical Physics

By T. M. Yarwood. 6*s.*

Elementary Dynamics of the Particle and Rigid Body

By R. J. A. Barnard. *Third Edition.* 5*s.*

Contributions to the Mechanics of Solids

Dedicated to Stephen Timoshenko. By Various Authors. 25*s.* net

Introduction to Contemporary Physics

By Dr. Karl Darrow. *Second Edition.* 25*s.* net

M.K.S. Units and Dimensions

By Prof. G. E. M. Jauncey and A. S. Langsdorf, M.M.E. 4*s.* net

MACMILLAN & CO. LTD.
St. Martin's Street, London W.C. 2

"NEVER IN THE FIELD OF HUMAN CONFLICT WAS SO MUCH OWED BY SO MANY TO SO FEW"

The Prime Minister

You can back up our airmen

by buying NATIONAL WAR BONDS, SAVINGS CERTIFICATES, DEFENCE BONDS, *or by depositing in the* POST OFFICE *or* TRUSTEE SAVINGS BANKS

Issued by the National Savings Committee, London

TWO SPECIAL PARTS OF THE

PROCEEDINGS OF THE PHYSICAL SOCIETY

Vol. 49, No. 274 (August 1937) 154 pages

and

Vol. 52, No. 290 (January 1940) 178 pages

consist of

REPORTS OF TWO CONFERENCES

held at the

H. H. WILLS PHYSICAL LABORATORY, UNIVERSITY OF BRISTOL

in JULY 1937 and JULY 1939

ON

CONDUCTION OF ELECTRICITY IN SOLIDS

and

INTERNAL STRAINS IN SOLIDS

Price 7*s*. each; post-free 7*s*. 5*d*.

Orders, with remittances, should be sent to

THE PHYSICAL SOCIETY

1 Lowther Gardens, Exhibition Road, London, S.W. 7

or to any bookseller.

For over 50 years now Taylor-Hobson have been producing highly-developed optical equipment and precision machinery. This dual experience places us in an unique position in the Engineering Industry inasmuch that we are familiar with the problems of the one and the potentialities of the other.

Primed in this way we have successfully produced a range of instruments to meet the gauging and measuring requirements of practically every section of the Engineering Industry.

If you have any such problems which seem unusually difficult bring them to us, we are well qualified to assist you.

PROFILE PROJECTORS · ELECTROLIMIT GAUGES

ALIGNMENT TELESCOPES · ENGRAVING MACHINES

JAVELIN ETCHERS · COOK LENSES AND PRISMS

TAYLOR-HOBSON

(TRADE MARK)

TAYLOR, TAYLOR & HOBSON LTD., STOUGHTON ST. WORKS, LEICESTER & LONDON

Pitchfords 2049

What the RED CROSS is doing

CENTRAL HOSPITAL SUPPLY SERVICE

This branch of the RED CROSS supplies materials for work parties. Materials are issued in quantities which enable the Work Parties to make the required number of garments, bandages, swabs, and surgical necessities.

WORK PARTIES

There are 5,000 Work Parties at home and overseas occupied with RED CROSS work. They have made 800,000 garments and 400,000 bandages.

CENTRAL SUPPLY STORES AND COUNTY STORES

In London three central stores are maintained by the RED CROSS. They contain large reserves of hospital supplies and equipment. Ninety stores have been established in other parts of England and Wales. Into these stores go many of the articles made by the Work Parties from the materials issued by the Central Hospital Supply Service.

The Appeal on behalf of H.R.H. The Duke of Gloucester's Red Cross and St. John War Organisation Fund has now produced £4,200,000. Much more money, however, is needed unless Red Cross activities are to be curtailed, which is unthinkable.

Subscriptions should be sent to the Lord Mayor's Red Cross and St. John Fund, The Mansion House, London, E.C. 4.

Red Cross gratefully acknowledges free gift of this space.

LOW LOSS MAGNETIC ALLOYS

MUMETAL
Highest permeability at low inductions.

RHOMETAL
High permeability and low loss at elevated frequencies.

RADIOMETAL
High permeability at high inductions and high incremental permeability.

TELCON METALS

TELCON METALS are produced under close technical control and are sold to specification of magnetic properties.

Brochure giving complete technical data will be supplied on request.

THE TELEGRAPH CONSTRUCTION & MAINTENANCE CO. LTD.

Head Office: 22 OLD BROAD STREET
LONDON, E.C.2
Telephone: LONdon wall 3141

The Review of Scientific Instruments

Gaylord P. Harnwell, *Editor* (*University of Pennsylvania, Philadelphia, Pennsylvania*)

Published monthly by the American Institute of Physics, this journal brings to you the latest research developments on instruments and apparatus.

Its Table of Contents includes:

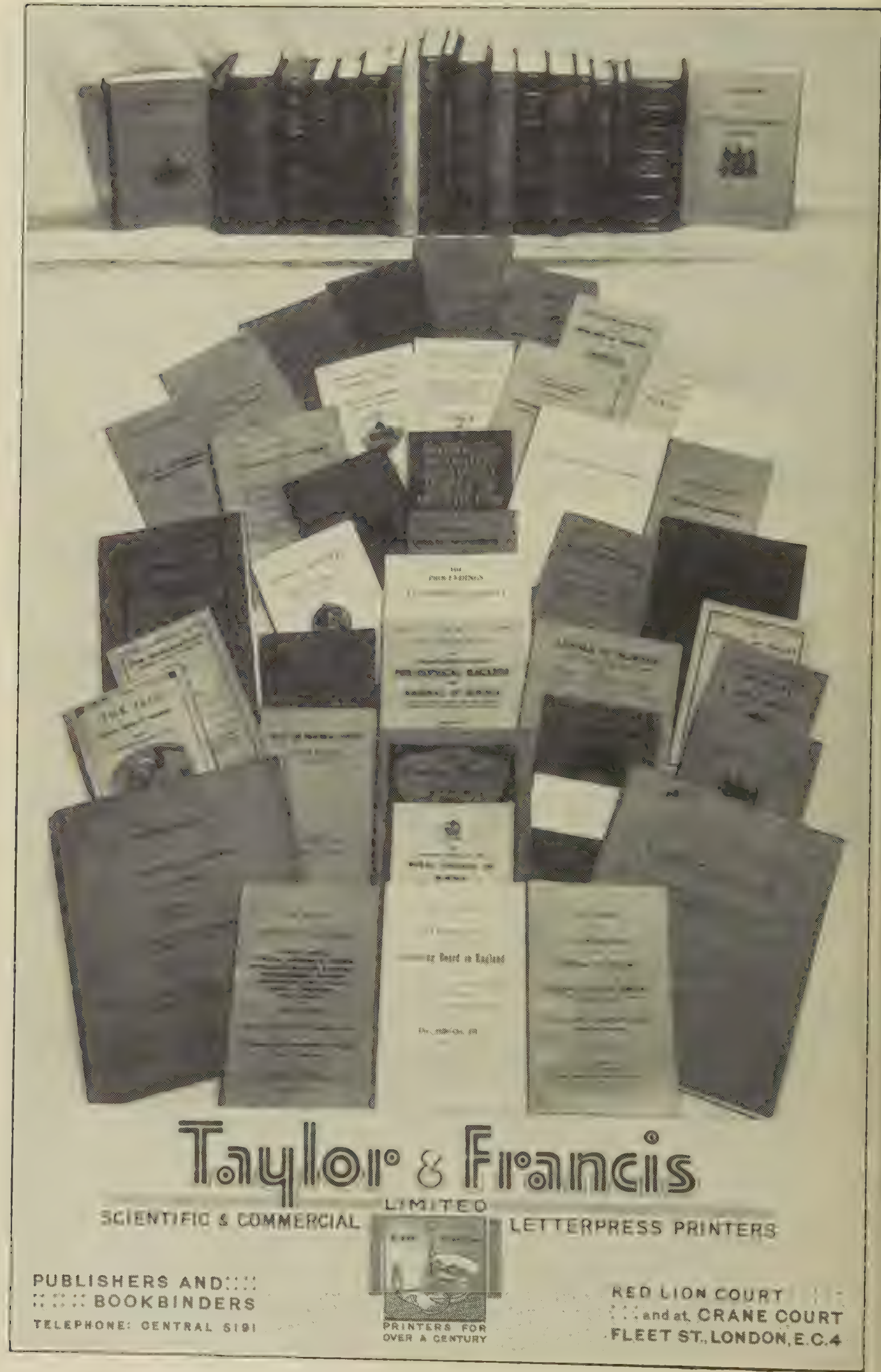
- **Contributed Articles**: Reports of research on instruments and apparatus.
- **Laboratory and Shop Notes**: Brief accounts of new methods or apparatus.
- **Current Literature of Physics**: Tables of contents of physics magazines all over the world.
- **Book Reviews** (April and October issues).
- **Brief Notes** on new instruments and materials.

Subscription price for the U.S. and Canada, $3.50 *a year*; *Elsewhere,* $4.00 *a year.*

The American Institute of Physics Incorporated

175 Fifth Avenue, New York, New York, U.S.A.

Publishers also of the following physics journals	YEARLY SUBSCRIPTION PRICE U.S. AND CANADA	ELSEWHERE
THE PHYSICAL REVIEW	$15.00	$16.50
REVIEWS OF MODERN PHYSICS	4.00	4.40
JOURNAL OF APPLIED PHYSICS	7.00	7.70
JOURNAL OF CHEMICAL PHYSICS	10.00	11.00
JOURNAL OF THE OPTICAL SOCIETY OF AMERICA	6.00	6.60
JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA	6.00	6.60
AMERICAN JOURNAL OF PHYSICS (*Formerly The American Physics Teacher*)	5.00	5.50


Taylor & Francis
LIMITED
SCIENTIFIC & COMMERCIAL
LETTERPRESS PRINTERS
PUBLISHERS AND
BOOKBINDERS
TELEPHONE: CENTRAL 5191
PRINTERS FOR OVER A CENTURY
RED LION COURT
and at CRANE COURT
FLEET ST., LONDON, E.C.4

THE MODERN THEORY OF SOLIDS

By FREDERICK SEITZ

Assistant Professor of Physics, University of Pennsylvania

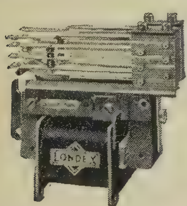
698 pages, 9 × 6, illustrated. 49/- net

(International Series in Physics)

Chapter Headings

- Preface
- Commonly Used Symbols
- Empirical Classification of Solid Types
- The Classical Theory of Ionic Crystals
- The Specific Heats of Simple Solids
- The Free Electron Theory of Metals and Semi-conductors
- Quantum Mechanical Foundation
- Approximate Treatment of the Many-body Problem
- Molecular Binding
- The Band Approximation
- Approximational Methods
- The Cohesive Energy
- The Work Function and the Surface Barrier
- The Excited Electronic States of Solids
- The Electronic Structure of the Five Solid Types
- The Dynamics of Nuclear Motion. Phase Changes
- Theory of Conductivity
- The Magnetic Properties of Solids
- The Optical Properties of Solids
- Appendix
- Author Index
- Subject Index

McGraw-Hill Publishing Company Ltd.
Aldwych House **London, W.C.2**

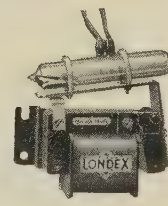


Multiple Contact Relay Type LF.

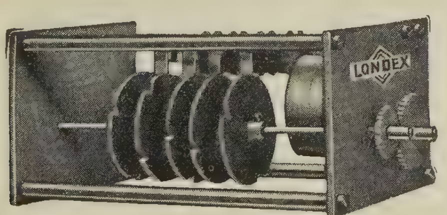
RELAYS

Relays for A.C. and D.C. **SILENT & RELIABLE**

2 VA coil consumption, from 2–600 volts, tested to 2,000 volts. Unmounted and in cast iron casing. Also Time Lag Relays. High Sensitive Relays, Complete Control Plants.



Mercury Relay Type LQA.



Synchronous Motor Driven Process Timer. Easily interchangeable gear wheels.

Up to 14 cams.

PROCESS TIMERS

Ask for particulars

LONDEX LTD.

Electrical Remote Control Engineers and Manufacturers,

Anerley Works, 207, Anerley Road, London, S.E. 20.

Telephone SYDenham 6258–9.

REPORTS ON PROGRESS IN PHYSICS

VOLUME VII (1940)

A comprehensive review by qualified physicists under the general editorship of

J. H. AWBERY, B.A., B.Sc.

Ready Shortly

About 350 pages ***Illustrated*** ***22s. 6d. post free*** ***Bound in cloth***

The new volume includes articles on:

SOUND
MUSICAL ACOUSTICS
SURFACE TENSION
EQUATIONS OF STATE
SOME INTERACTIONS OF GASES WITH SOLIDS
VISCOSITY AND THE NATURE OF SUBSTANCES OF HIGH MOLECULAR WEIGHT IN SOLUTION
ELECTRICAL DISCHARGES IN GASES
ELECTRON MICROSCOPES OF HIGH MAGNIFICATION
NEW LENS SYSTEMS
PHOTO-ELECTRIC SPECTROPHOTOMETRY
INFRA-RED SPECTRA OF POLYATOMIC MOLECULES
SOLAR PHYSICS
ABSORPTION OF LIGHT IN INTERSTELLAR SPACE
GAMMA RADIATIONS EMITTED IN NUCLEAR PROCESSES
THE BOHR THEORY OF NUCLEAR REACTIONS
TEACHING OF EXPERIMENTAL PHYSICS IN UNIVERSITIES

Volumes III (1936), V (1938) and VI (1939) are still available—prices 20*s*., 20*s*. and 22*s*. 6*d*. respectively, inclusive of postage

Orders, with remittances, should be sent to

THE PHYSICAL SOCIETY

1 Lowther Gardens, Exhibition Road, London, S.W. 7

or to any bookseller

THE MATERIAL OF INFINITE USES...

BAKELITE Moulding Materials

BAKELITE Laminated Materials
For Electrical Insulation, Aircraft Components, Silent Gears, Interior Decoration.

BAKELITE Synthetic Resins
For Insulating Varnishes, Cements, Lacquers, Durable Finishes.

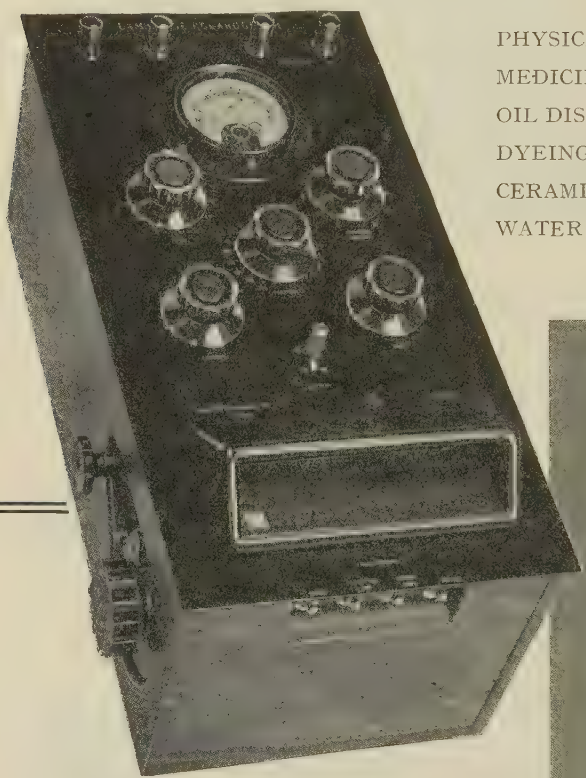
BAKELITE
Registered Trade Marks
TREFOIL

BAKELITE LIMITED
Brackley Lodge, Brackley, Northants.

LONDON OFFICE, 18 Grosvenor Gardens, S.W.1

CAMBRIDGE POLAROGRAPH

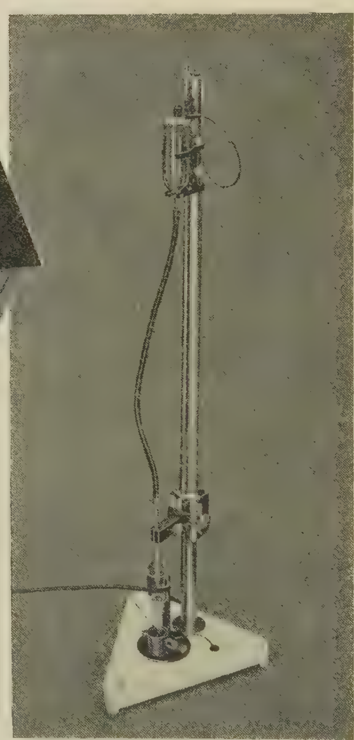
(HEYROVSKY DROPPING MERCURY ELECTRODE METHOD)



Some Fields of Application:

PHYSICAL CHEMISTRY	METALLURGY
MEDICINE	MINERALOGY
OIL DISTILLING	SUGAR
DYEING & BLEACHING	EXPLOSIVES
CERAMICS	GASES
WATER PURIFICATION	AGRICULTURE

etc.



This new Cambridge instrument provides a valuable means for the rapid electro-chemical analysis of solutions, enabling traces of metals and many acid radicals and organic substances to be determined.

Full details are given in ***SHEET No. 240-L.*** *May we send a copy ?*

91

CAMBRIDGE INSTRUMENT COMPANY LTD.
13, GROSVENOR PLACE, LONDON, S.W.1.
WORKS: LONDON & CAMBRIDGE.

THE PROCEEDINGS OF THE PHYSICAL SOCIETY

VOL. 53, PART 1 — 1 January 1941 — No. 295

ERNEST ORLANDO LAWRENCE

SEVENTEENTH DUDDELL MEDALLIST

THE seventeenth award of the Duddell Medal of the Physical Society has been made to Professor Ernest Orlando Lawrence of the University of California, Berkeley. By its decision the Council of the Society will have won the wholehearted approval not only of the members of this Society, but of physicists and scientists throughout the world—or those parts of it where progress and enlightenment may still freely be assessed at their true worth.

The Duddell award to Professor Lawrence has been for " the invention and development of the cyclotron ". *Inception* might perhaps be a more apt descriptive term than *invention*. The idea of magnetic resonance acceleration came to Lawrence immediately after reading a paper by Wideröe describing the successful application of the principle of linear resonance acceleration; the development of the cyclotron, however, to its present stage has taken ten years of patient research, research which was started by Lawrence with typical optimism despite the doubts entertained by his immediate associates as to its successful issue.

The technical details regarding the development and operation of the cyclotron have, even if inadequately, been already chronicled for the benefit of the members of this Society.* A repetition of those details at this juncture would be rendering but further injustice to an instrument which, for brilliance of conception, and simplicity of principle, must be considered, along with the cloud chamber, as one of the most satisfying tools at the service of nuclear physics.

Thus a few words instead about the seventeenth Duddell medallist himself might be of more value; for members this year will be denied the pleasure of a personal award, and many too will not already be acquainted with Professor Lawrence since the vicissitudes of fate, or politics, have made him but a rare visitor to Europe in recent years.

Born in 1901, Ernest Lawrence attended the University of South Dakota, his native state, and then continued with post-graduate work successively at the Universities of Minnesota and Chicago and, finally, at Yale, obtaining his Ph.D. degree from this last University in 1925. The reason for this rapid succession of changes, from one University to another, during Lawrence's post-graduate

* *Rep. Progr. Phys.* **6**, 125 (1939).

years is one which cannot but appeal to the members of this Society through the very aptness of the link which it creates. At Minnesota Lawrence became associated with W. F. G. Swann, a member of this Society and also an Associate of the College with which many of the activities of the Society have been connected. The association thus formed was not to be broken by the movements of Dr. Swann, first from Minnesota to Chicago and thence to Yale; Lawrence accompanied him. From Yale, where he became an assistant professor, Lawrence went to the University of California at Berkeley as an associate professor in 1928 and has there remained, being appointed professor in 1930.

The first cyclotron, constructed by Lawrence and Edlefsen in 1930, was contained in a glass envelope four inches in diameter; with it the resonance effect was observed. The first cyclotron to give protons with energies of more than a million volts was constructed by Lawrence and Livingston, and was afterwards exhibited in the Science Museum at South Kensington.

The subsequent 37-inch cyclotron, which has rendered such long service in the Radiation Laboratory at Berkeley, was designed by Professor Lawrence and Dr. Donald Cooksey, and can be seen in the pictures of the medallist given in figures 1 and 2 (plate 1). Its 85-ton electromagnet was one of four that had been built for long-distance radio transmission during the last war, but was still undelivered when the war ended, and had lain idle ever since. At one time in 1938 pressure of work made it necessary for the 37-inch cyclotron to be run to a 22-hour daily schedule. Usually Lawrence was himself to be found in the laboratory from early morning until late at night; even if occasionally he did stay at home for the evening he had only to tune in his radio set to about 26 m. to know whether or not the cyclotron were still running. If there were any kind of a breakdown Lawrence would soon be telephoning to the laboratory to know what the trouble might be; and no one had the skill of Lawrence in finding the causes of such breakdowns! Nor would anything but perfect running satisfy him. If the maximum beam were not being obtained then a period would be set aside for adjustments, in which he usually took a very active part. The laboratory was run on a co-operative basis, members of the laboratory taking turns to run the cyclotron for the use of other members, and no visitor to the laboratory was too distinguished to do his share of the routine work if he wished to use the cyclotron.

The 220-ton cyclotron of the William H. Crocker Radiation Laboratory at Berkeley has a vacuum chamber 60 inches in diameter. With this cyclotron, photographs of which are shown in figures 3 and 4 (plate 2), 100 micro-amperes of 16-million volt deuterons can be obtained. And now from Berkeley comes the news that funds have been granted by the Rockefeller Foundation for the construction of a giant cyclotron the magnet of which alone will weigh approximately 4900 tons. The diameter of the pole faces of this magnet will be 184 inches and their separation about 40 inches. According to a recent statement by Dr. Cooksey, assistant director of the Radiation Laboratory, it is hoped to obtain 100-million volt deuterons with this cyclotron,

Perhaps one of the most interesting of the cyclotron's many and diverse applications has been the use of radioactive indicators, or so-called "labelled atoms", in chemistry and biology. The production of large quantities of artificially radioactive elements such as phosphorus, iron and sodium has completely revolutionized the study of metabolism. And now recently a new radioactive carbon isotope, of atomic mass 14 and having a half-life of several years, has been found at Berkeley. The potentialities of a long-lived artificially radioactive isotope of one of the most widely distributed and important elements in nature will be considerable, and we may anticipate many years of fruitful research with this new "labelled atom". Other interesting applications of the cyclotron have been in the production of neutrons for the treatment of cancer and of artificially radioactive phosphorus for the treatment of chronic leukæmia.

As the originator of the cyclotron and the head of the foremost American school of investigators of nuclear transmutation and artificial radioactivity, Lawrence has been widely honoured. In 1937 he received the Comstock Prize of the National Academy of Sciences, which is awarded only once in five years and is the highest honour of the Academy, if not the highest scientific honour in the United States. In 1938 he was awarded the Hughes Medal of the Royal Society, and in 1939 the Nobel Prize in Physics.

Incredulity is one of the most common reactions to the performance of the Berkeley cyclotrons. But to know Ernest Lawrence is to know too why it is that the Berkeley cyclotrons give such incredible results. In the face of such irrepressible enthusiasm and such *joie de vivre* difficulties hardly stand a chance, and faced too by his deep innate *sense* of physics they merely stand to fall. And in trying to appreciate that irresistible drive in the laboratory one cannot but recall the boisterous enthusiasm of Lawrence away from work. He might return from a ski-trip with an injured arm or be hobbling around the laboratory with a stick for some days after; but so soon as the opportunity returned he would launch himself as joyously as before over the brink of some snow-clad slope. One also recalls wildly happy days (equally unreal and like some far-off pleasant dream !) on some Pacific beach or in his motor-cruiser on San Francisco Bay. "Ernest carries a chart in his boat", said one of his friends, "so that he'll know what mud-bank he is stranded on".

And with his enthusiasm Lawrence combines a quality which enables him to obtain from his assistants (friends would be a better term !) in the Radiation Laboratory devoted and loyal service. That quality is complete selflessness. Professor Birge, at the presentation of the Nobel Prize to Lawrence, quoted the first remark of Lawrence on being informed of that award, namely: "It goes without saying that it is the laboratory that is honoured, and I share the honours with my co-workers past and present". And once again, responding at the presentation of the Nobel Prize, Lawrence gave full and generous credit to his friends and colleagues. His closing words were: "May I again give expression to a profound feeling of gratitude and appreciation for this great honour, which

I share with the university and with all those outside who have contributed to make our work possible and, above all, with my valued colleagues and co-workers both past and present ".

At this time, when so much of what we value is being preserved and developed in the laboratories of North America, the award of the 17th Duddell Medal to a great American physicist acquires a symbolic significance. The formal presentation of the medal to Professor Lawrence was made at Philadelphia on the 27th December 1940, the occasion being that of a dinner in connection with a three-day meeting of the American Physical Society, with its President, Professor John Zeleny of Yale University (a former pupil of Sir Joseph Thomson at the Cavendish Laboratory) in the Chair. The late Marquess of Lothian, H.M. Ambassador in Washington, had kindly promised to present the Medal to Professor Lawrence. After his untimely death, of which members of both Societies will have heard with profound regret, other arrangements were made, and Mr. Neville Butler, First Counsellor to the Embassy and H.M. Chargé d'Affaires *ad interim* in Washington, took Lord Lothian's place at the presentation.*

W. B. M.

Description of plates

PLATE 1: Ernest Orlando Lawrence. (Photographs by Mr. Horace Bristol.)

Figure 1. In the left foreground of this picture is the vacuum tank located between the pole-pieces of the 37-inch cyclotron at Berkeley. The wheels which can be seen are two of four provided to facilitate the placing of the vacuum chamber into its proper position between the pole-pieces of the electromagnet and its removal when necessary.

Figure 2. In the foreground of this picture can be seen the dee supports mounted on their cylindrical glass insulators, with connecting tubes for the supply of cooling water.

PLATE 2: The 220-ton 60-inch cyclotron of the William H. Crocker Radiation Laboratory, University of California, Berkeley, California. (Photographs by Dr. Donald Cooksey; reproduced through the courtesy of the Editors of *Nature*.)

Figure 3. Above the cyclotron to the left can be seen the oscillators for generating the high-frequency voltage to be applied to the dees. To the left of the vacuum chamber, which is located between the pole-pieces of the magnet, can be seen the target chamber into which the beam of high-energy ions emerges. This target chamber can be distinguished by its two port holes. At the corner of the magnet is the late Dr. Harold Walke of the University of Liverpool.

Figure 4. The 16-million volt deuteron beam emerging from the target chamber of the 60-inch cyclotron with a range in air of nearly five feet. The beam passes through a thin aluminium window from the evacuated target chamber into the surrounding air. The violet colour of the glow caused by the beam is that characteristic of the electrical discharge in air. The yield of neutrons from the bombardment of beryllium with this deuteron beam is equivalent to that for which 200 lb. of radium would be required.

* The present article is based on the remarks made by the writer in proposing the health of the seventeenth Duddell Medallist at a luncheon held in London on the same date as the presentation in Philadelphia. [ED.]

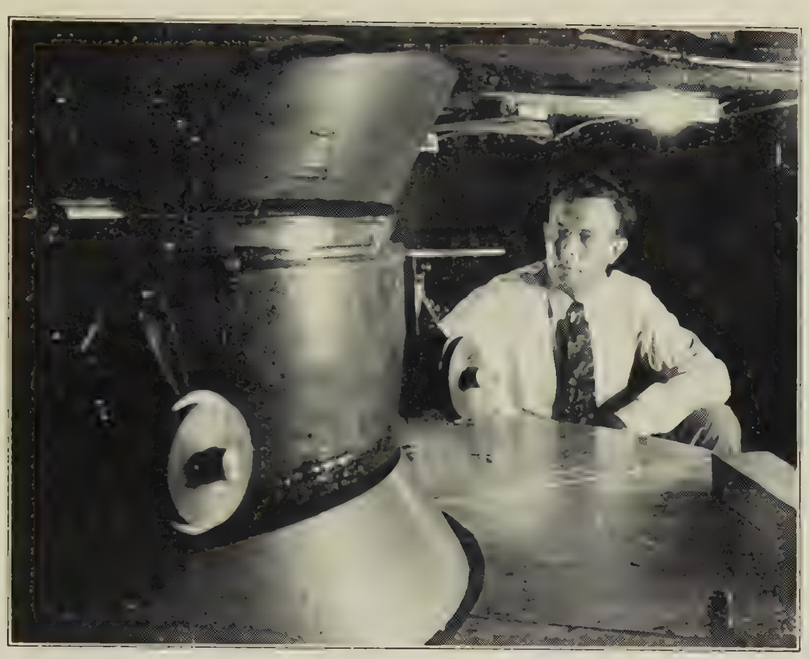


Figure 1.

Figure 2.

Plate 1. Ernest Orlando Lawrence.

To face page 4

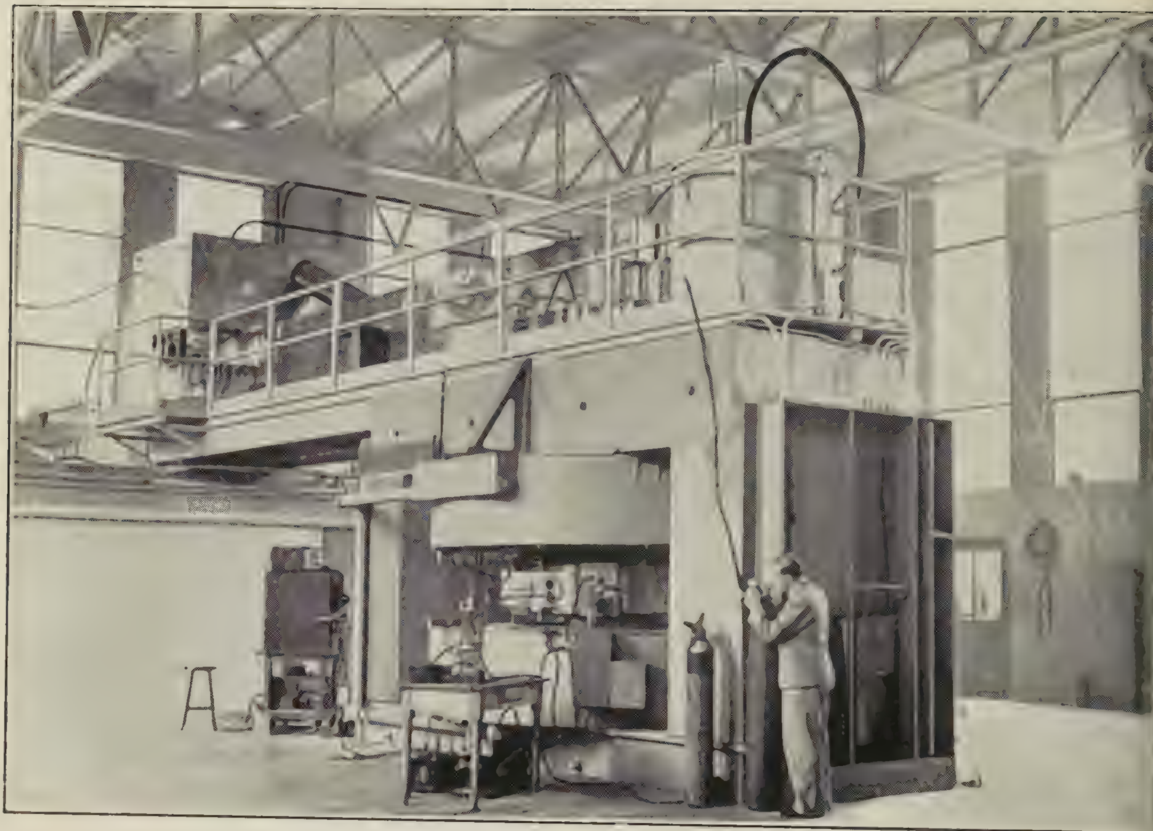


Figure 3.

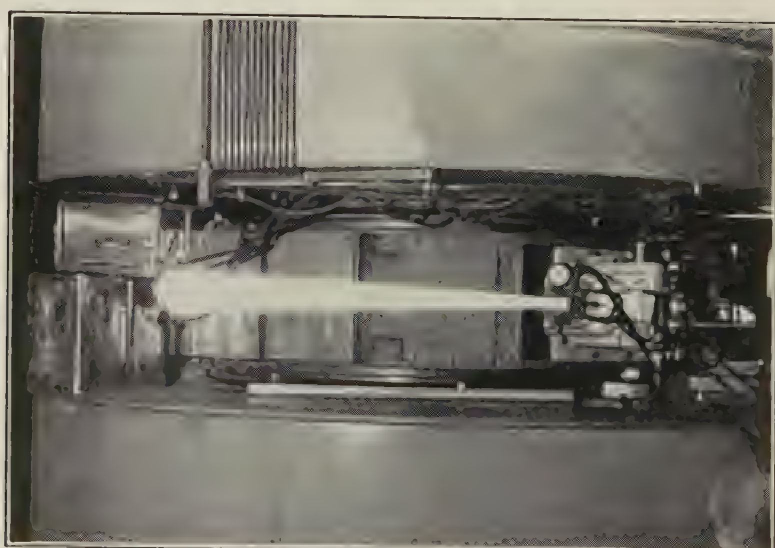


Figure 4.

Plate 2 The 220-ton 60-inch cyclotron of the William H. Crocker Radiation Laboratory, University of California, Berkeley, California.

THE ADIABATIC TEMPERATURE CHANGES ACCOMPANYING THE MAGNETIZATION OF FERROMAGNETIC MATERIALS IN LOW AND MODERATE FIELDS

By L. F. BATES and J. C. WESTON,
University College, Nottingham

Received 20 *July* 1940

ABSTRACT. A new and relatively simple method is described for the measurement of the heat changes which accompany magnetization processes in fields of the order of a few hundred oersteds. The adiabatic changes in temperature of a rod which occur when the latter is taken step-by-step through a hysteresis cycle are measured by a series of thermocouples of which the " hot " junctions are directly attached to the rod. The temperature-measuring system is capable of detecting changes in temperature of the order of 10^{-6} deg. C., and its sensitivity is such that 1 mm. scale deflection corresponds to the absorption or liberation of about 330 ergs per c.c. in the specimen, deflections of 0·1 mm. being easy to read.

Experiments made with pure annealed and hard-drawn nickel and with certain nickel-iron alloys, strained and unstrained, are described, and many graphs are given to show the observed temperature changes as functions of the intensity of magnetization and of the applied field. The results provide a very effective proof of Warburg's law, but their main importance is that they enable a detailed analysis of the energy changes accompanying magnetization to be made. They show that Becker's views on magnetization processes in ordinary ferromagnetic materials are essentially correct, but do not support Preisach's conception of the formation of demagnetization nuclei in the case of extremely soft ferromagnetic materials.

§ 1. INTRODUCTION

THE study of the magnetocaloric effect or the reversible changes in temperature which accompany magnetization has added much to our knowledge of the behaviour of the spontaneous magnetization of ferromagnetics. It is well known that on placing a paramagnetic or a ferromagnetic substance in a very strong field an adiabatic rise in temperature is observed, and a corresponding fall in temperature when the substance is removed from the field. The fields employed in such experiments are so intense that ordinary hysteresis phenomena, which are confined to fields of some few hundred oersteds, do not play a part. It is correct to say that very much more is known about temperature changes accompanying magnetization processes in very strong fields than about those in

weak ones. In this communication are presented the results of an investigation of the temperature changes which occur when a ferromagnetic is taken through an ordinary technical hysteresis cycle.

It is generally accepted that the energy liberated in a complete hysteresis cycle can be obtained from the expression $\oint_{+H}^{+H} HdI$, a statement which is sometimes known as Warburg's law (1881). The derivation of this expression has recently been discussed by Becker and Döring (1939), Bitter (1937), Guggenheim (1936), Stoner (1937) and others; it is rigidly correct only when the conductors present consist solely of the specimen and the solenoid which produces the magnetic field applied to it, so that eddy currents are not established in neighbouring conductors. The above treatments, however, are not adequate for a discussion of the energy changes associated with small changes in H in any part of a hysteresis cycle. In what follows we shall therefore use a method of analysis suggested privately by Professor Stoner.

We shall suppose that HdI correctly represents the energy supplied to a ferromagnetic specimen in any part of a hysteresis cycle and that it is accompanied by an increase in internal energy dE. For the present, we will confine attention to specimens which are not subjected to applied mechanical forces, so that we may write

$$HdI = (\partial E/\partial I)_T\, dI + (\partial E/\partial T)_I\, dT. \qquad \ldots\ldots(1)$$

Now, HdI can be obtained from magnetic measurements, while the second term on the right-hand side of equation (1) represents that part of the internal energy which manifests itself as an increase in temperature and can be obtained directly from the thermal measurements described below. In fact, we may write

$$(\partial E/\partial I)_T\, dI = dE_1 = HdI - dQ, \qquad \ldots\ldots(1\,a)$$

and we can therefore determine $(\partial E/\partial I)_T$ at any stage in the magnetization of a ferromagnetic, i.e. we can say whether E increases, decreases or remains constant with change in I at any point on an (I, H) curve. Equation (1 *a*) is, of course, independent of whether the change is reversible or not.

There are considerable difficulties in the way of the accurate determination of dQ, for in the study of soft materials by a step-by-step procedure, it is necessary to detect changes in temperature of 10^{-6} °c.; consequently, few such measurements have been carried out. A pioneer investigation was made by Adelsberger (1927), who measured the changes of temperature which occurred in a hard steel rod 15 cm. long and 1·5 cm. in diameter. He found that $\oint_{+H}^{+H} HdI$ correctly represented the total energy dissipated when 1 c.c. was taken through a complete cycle, although the difference between the liberated energy calculated from the (I, H) curve and that measured directly was sometimes as much as 10 per cent. Similar experiments were carried out by Constant (1928) with rings of "K.S. Magnet Steel".

Experiments confined to carbon steels with a coercivity of 9·6 oersteds were made by Ellwood (1929), whose test specimen consisted of 104 steel rods of 1 mm. diameter, mounted with an equal number of copper rods of the same dimensions. The whole collection of rods was symmetrically packed to give a composite specimen roughly the shape of an ellipsoid of revolution, with a major axis 60 cm. and a minor axis 3·4 cm. long. Adjacent copper and iron rods were joined alternately by short pieces of copper and constantan wire to constitute a series of 102 thermocouples in series. The specimen was embedded in rice flour and placed in an evacuated tube surrounded by two hard-rubber tubes separated by an air space. Ellwood states that a temperature change of $2{\cdot}26 \times 10^{-6}$ °c., corresponding to a change in thermal energy of 87 ergs per c.c. of steel, gave a deflection of 1 mm. on his galvanometer scale. Similar experiments were made by Honda, Ôkubo and Hironé (1929) and by Okamura (1936).

Experiments on nickel were made by Miss Townsend (1935), who used a specimen in the form of a wire, 1 mm. in diameter and 35 cm. long, placed axially within the cylindrical calorimeter and solenoid used earlier by Ellwood. Sixty thermocouples with junctions electrically insulated from the rod were joined in series to a sensitive galvanometer. Miss Townsend calibrated the system by sending a direct current of known strength through the specimen for a short interval of time, and 1 mm. on the galvanometer scale corresponded to 629 ergs per c.c.

Miss Townsend's work has been superseded in some particulars by that of Hardy and Quimby (1938), who used a wire specimen 30 cm. long and 1 mm. in diameter, with 57 thermocouples connected in series to a galvanometer. The appropriate junctions were attached to the specimen by insulating cement. Hardy and Quimby considered that this method of attachment, with the minimum of constraint, explained certain differences between their results and those of other workers which they held to be in error. The galvanometer deflections were amplified by a photo-electric cell device, the final sensitivity being about 180 ergs per c.c. per mm.

The several investigations have been outlined in order to give some conception of the experimental difficulties. All suffered from drift of the galvanometer zero, and the complicated techniques used to avoid this drift meant that measurements were slow; for example, Okamura reported that his apparatus took 17 to 20 hours to reach a steady state. When there was electrical insulation between the thermojunctions and the ferromagnetic, loss of efficiency resulted. In most cases there was no method of calibrating the system used for the temperature measurements except by relying entirely on the magnetic ones. In all there was no possibility of varying the experimental conditions; for example, the ferromagnetic could not be subjected to a known stress during examination. The use of multiple specimens restricted the measurements to materials available in quantity. The method now to be described is free from all these disadvantages.

§ 2. THEORY OF NEW METHOD

The new method enables us to measure true adiabatic temperature changes as follows. One junction of a copper-constantan thermocouple is fixed to the specimen while the other junction is quite close to it, but thermally insulated from it except for conduction along the material of the couple. The latter is connected in series with a coil of low resistance wound as a primary on a mu-metal spiral core or ring. A secondary coil wound on the same core has a large number of turns of low resistance and is placed in series with a specially designed moving-coil galvanometer which is virtually a fluxmeter. The number of thermocouples to be employed is limited only by practical considerations. In our final arrangement we employed 20 such couples, and the sensitivity normally attained was 8×10^{-6} °C. per mm. deflection, but, as it was easily possible to read the deflection to at least 0·1 mm., the smallest temperature change which could be measured consistently was always less than 10^{-6} deg. C.

The following theory of the method, though obviously incomplete, nevertheless serves as an adequate basis for discussion. Let n_1 be the number of turns of the primary coil, A the mean area of cross-section of the mu-metal core of permeability μ, d its mean diameter, dE/dT the thermoelectric power of the thermocouple, and R the total resistance of a primary circuit. When the temperature of one of the thermojunctions changes by ΔT, a current $i = \frac{1}{R} \cdot \frac{dE}{dT} \cdot \Delta T$ flows in the primary circuit. It is assumed that this current remains constant, so that a change in induction persists for a sufficient interval of time. This condition appeared to be well satisfied in our experiments, but, in any case, the method of calibration really avoids difficulties which might arise if it were not. If the secondary on the mu-metal core has n_2 turns connected to a fluxmeter or highly damped galvanometer of long period, we obtain a deflection

$$\theta = \frac{4\mu n_1 n_2 A}{N'A'H'dR} \frac{dE}{dT} \cdot \Delta T, \qquad \ldots\ldots(2)$$

where N' is the number of turns on the moving coil of the instrument, A' its area and H' the field in which it moves. It is evident that a series of P thermocouples, each with its own primary winding, may be used to produce a deflection P times as large, each "hot" junction being placed in direct contact with the specimen. Such a system is singularly free from slow zero changes, because the thermocouples can be so well distributed along a specimen that their fluctuations cancel, and because slow changes produce drifts of zero which are insignificant compared with the rapid changes brought about by the experimental changes in ΔT.

Although equation (2) shows that θ is directly proportional to μ, there is in practice a limit to the value of θ, since when μ is increased the inductances in the galvanometer and thermocouple circuits are correspondingly increased, and consequently, unless the period of the instrument is also increased the moving system cannot acquire the maximum momentum which the simple theory assumes.

It is not considered worth while, in view of the periods which we were able to attain, to attempt to give a more complete theory in which the effects of self-inductance are considered.

§ 3. DESCRIPTION OF APPARATUS

Equation(2) shows that the deflection θ depends upon $N'A'H'$, and it is essential that H' should be adjustable. Accordingly, a moving-coil instrument was constructed with an electromagnet in place of the usual permanent magnet. The instrument is shown in figure 1. The yoke and pole pieces of the electromagnet were made of dead mild steel. The two magnetizing coils were each of 1800 turns of No. 22 S.W.G. double cotton-covered copper wire, wound on brass formers. The moving coil C was suspended by a fine fibre F of unspun silk about 15 cm. long attached to the copper wire Cu. Current entered and left the coil through

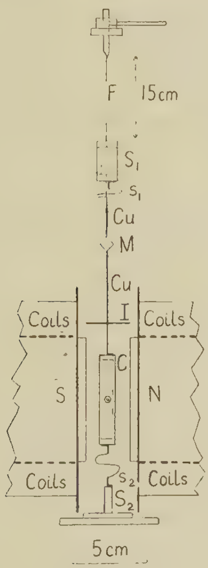


Figure 1. Design of special galvanometer with ferromagnetic control device.

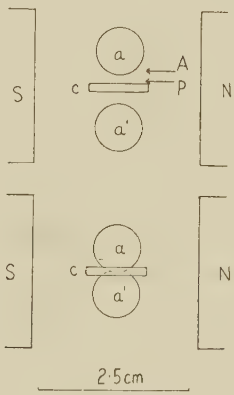


Figure 2. Method of obtaining non-uniform magnetic field.

very thin strips s_1, s_2 of silver, of total length 5 cm., width about 0·01 cm. and thickness (calculated from resistance measurements) about 0·0001 cm. Each strip was attached at the remote end to a support S_1, S_2 which could be rotated. The moving coil was wound with No. 40 S.W.G. double silk-covered copper wire. A thin plane mirror M of high quality was fastened to Cu, the telescope and scale being placed about 6 metres from the mirror, a distance comparable with that used by other workers.

The sensitivity varied with the number of turns on the moving coil and, with the materials used, reached a maximum at about 30 turns ; this number was therefore adopted. We encountered two main difficulties in obtaining sufficient

sensitivity. Firstly, even with the best silver strip we could procure, the leads still exerted an appreciable restoring couple. Secondly, very slight ferromagnetic impurities in the copper wire or its covering could give rise to very serious controlling couples. Eventually, it was decided to make use of the ferromagnetic impurity by causing it to produce a negative instead of a positive restoring couple, which is understood to be similar to a feature of one pattern of galvanometer on the market. In figure 2, a and a' represent two cylindrical soft-iron cores and C the moving coil between the pole pieces N, S of the electromagnet. The field at a point P is clearly less than the field at a point A. Consequently, when the coil is slightly displaced from the position of symmetry which it occupies in the figure, it is acted upon by a displacing couple which can be made approximately proportional to the angle of displacement by choosing suitable cores a and a'.

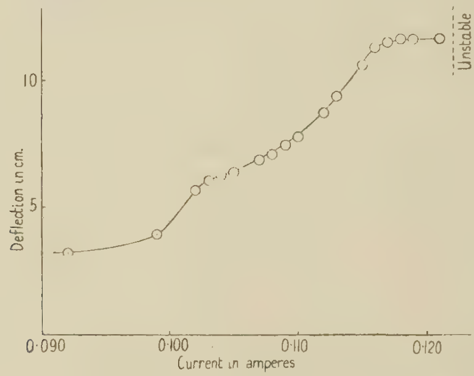


Figure 3. Variation of instrument sensitivity with field current.

It is thus possible to annul small torsional restoring couples. The type of core finally adopted is shown to scale in the lower portion of figure 2. This gave a linear relation between θ and ΔT as well as a reasonably stable zero. A small portion, about 0·3 mm. in thickness, was filed from each of two soft iron cylinders of diameter 0·79 cm., and the flat surfaces were held in contact by a nut and bolt. The quantity of ferromagnetic impurity in the coil was adjusted by the addition of small pieces of very thin brass wire.

The way in which the sensitivity varies with the electromagnet current for a chosen zero setting of the moving coil is shown in figure 3, where the deflection observed for a standard temperature change is plotted against the current. We see that there is a flat maximum which is particularly helpful in ensuring a constant sensitivity during a long experiment. The actual position of the maximum sensitivity with respect to the current is liable to vary appreciably with the setting of the coil, but the curve of figure 3 is fairly representative. The period of oscillation was generally of the order of 40 to 45 seconds. The inertia bar I provided additional stability. It is necessary to record one feature of the instrument's behaviour which was somewhat unexpected. It occasionally happened that, for no apparent reason, unless it was that unknown to us the coil accidentally

touched the iron core, the sensitivity suddenly became very low. It could be restored by reversing the maximum current in the electromagnet coils, breaking the circuit, and then supplying current in the original direction, and gradually increasing it to the optimum value. The sensitivity was closely watched during the course of each experiment by observing periodically the deflection produced by the reversal of a standard current in a subsidiary coil wound on the mu-metal core. Figure 3 shows, of course, that the simple theory of the instrument given here is incomplete, and that the resistance of the secondary circuit plays an important part.

The core was a spiral of mu-metal tape of internal diameter 12·7 cm., external diameter 14·3 cm., and depth 2 cm. Its initial permeability was 30,000. The number of turns, n_1, was fixed at 30, and in order to keep the primary resistance as low as possible these were wound immediately upon the transformer core, and the secondary coil was wound over them.

The "hot" junction of each thermocouple was formed by soldering together strips of copper and constantan, which were made by rolling No. 20 S.W.G. wires to a width of 2 to 3 mm. The "cold" junction was formed where one of the leads of No. 18 S.W.G. 40-strand rubber-insulated copper flex joined the constantan. The distance between the "hot" and the "cold" junctions was about 1·5 cm. The copper and constantan strips were separated by a thin strip of mica held in position by insulating tape. Each hot junction was placed between a small ebonite ring and the ferromagnetic rod, and pressed lightly against the rod by means of a small screw in the side of the ring remote from the thermojunction, as shown in figure 4 (*a*), the junctions being arranged symmetrically around the rod.

The solenoid usually employed consisted of a water-cooled brass former 63·4 cm. long, wound in eight layers with 6143 turns of No. 22 S.W.G. double silk-covered copper wire, each layer being insulated from the next by a coating of paraffin wax. The internal diameter of the solenoid was 3·7 cm. and its external diameter 5·6 cm. It was set vertical, in a suitable wooden frame fixed to the floor, and the effect of the vertical component of the earth's magnetic field on the specimen was eliminated in the usual way. A series of resistances in parallel with the solenoid allowed the field to be varied in a number of steps. This arrangement has an important advantage over the more common circuit, in which a series resistance is increased in order to decrease the magnetizing current, with the result that the time factor is thereby decreased. With the parallel circuit the time factor increases when the current in the solenoid is decreased. Consequently, the steep portion of a hysteresis loop is traversed more slowly than the other portions, and, therefore, eddy-current effects, which are important when dB/dt is large, are correspondingly reduced. It is essential that the solenoid circuit should be thoroughly insulated.

The demagnetization factors (Bates, 1939) of the specimens were found by measurements with a special search coil, shown in figure 4 (*b*), so designed that

none of its turns of wire completely encircled a specimen, although practically the whole field region in the immediate neighbourhood of the middle portion of a specimen was enclosed. In any case, with specimens of the dimensions chosen, an error in the demagnetization correction was rarely important.

Mounting of the specimen

The specimen Ni was mounted inside the solenoid as shown in figure 4. Screw threads were cut on its ends so that it could be coupled to two brass extension

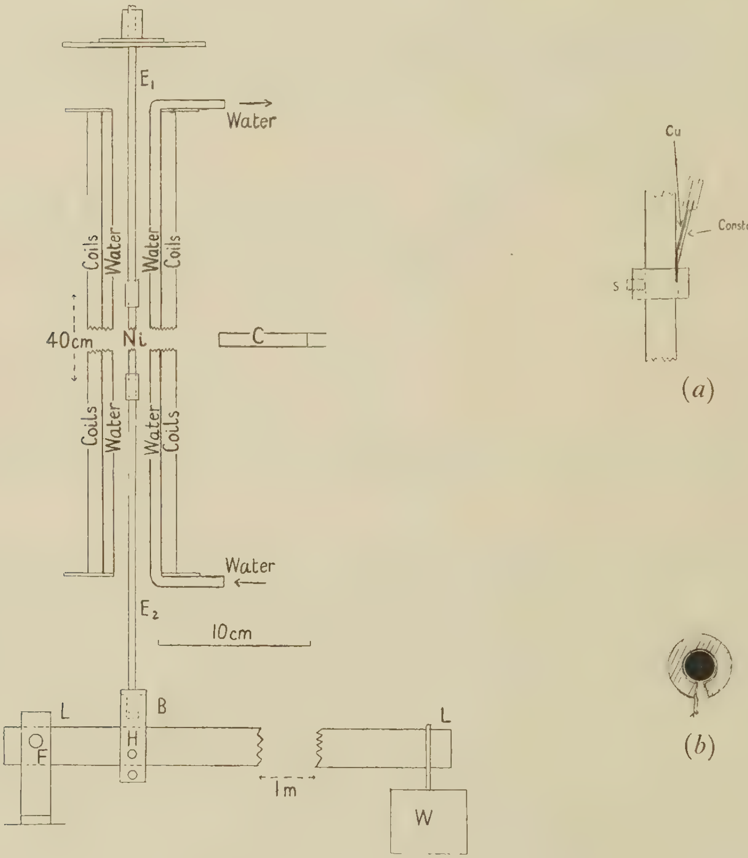


Figure 4. Mounting of the specimen.
(*a*) Method of making thermojunction contacts.
(*b*) Special search coil for finding the demagnetization factor of a specimen.

rods E_1 and E_2. The upper end of E_1 was provided with a nut which rested on a brass disk supported by a stout brass plate on a strong wooden platform, in order that large stresses might be applied to E_2 by means of the substantial brass lever LL, hinged at F. When the lever and weight W were used to apply a known tension to the specimen, the lever was kept horizontal by adjusting the nut on the

lower end of E_2 within the brass frame B, hinged at H. The use of the coil C will be described later. The thermojunctions were attached to Ni as described above, and the whole rod was then loosely wrapped in oiled silk.

Calibration of the apparatus

In order to test the existence of a linear relation between the deflection of the moving coil and the change of temperature which caused it, and also to calibrate the instrument, standard adiabatic changes of temperature of the order of 0·001° c. were produced by applying known longitudinal stresses to the specimen. Joule (1884) showed that when a tension of F dynes is suddenly applied to a metal rod there results an adiabatic fall of temperature ΔT given by

$$\Delta T = -\frac{\alpha TF}{J\rho sA} = -\frac{\alpha TF}{QA}, \qquad \ldots\ldots(3)$$

where α is the coefficient of linear expansion of the rod, T the absolute temperature, J the mechanical equivalent of heat, and ρ, s and A are the density, specific heat and area of cross-section of the rod respectively.

As a test, deflections were recorded on the application or removal of a series of loads to a specimen of mild steel. Equality to within 0·5 per cent was found between the deflections obtained on application or removal of a particular load, and the mean deflection was directly proportional to the load. Consequently, in order to calibrate a set of thermomagnetic readings, it is only necessary to apply or to remove one chosen load to the unmagnetized rod. The deflections can then be expressed as temperature changes immediately. Moreover, equation (3) may be rewritten as $Q\,.\,\Delta T = -\alpha TF/A$, where $Q\,.\,\Delta T$ is the energy in ergs required to raise the temperature of 1 c.c. of the specimen by $\Delta T°$ c., so that we do not need to know either the specific heat or the density of the material in order to express our results in the most convenient form. Provided that care is exercised in handling them, the thermocouples may be mounted on different occasions without change in deflection by more than 2 per cent, with the instrument working at a standard sensitivity.

Sources of error

It is convenient to distinguish between those sources of error common to all measurements of this kind and those peculiar to our method. Under the first heading are zero drift of the galvanometer, loss of heat and eddy currents; under the second heading are the effects of the solenoid field on the mu-metal core and on the thermocouple leads.

Our experiments were almost entirely free from zero drift under normal conditions. The method of calibration employed in our work automatically eliminated errors due to loss of heat, provided that the heat of magnetization processes and of mechanical distortion are supplied at approximately the same rates to the specimen. Apart from materials which exhibit pronounced magnetic viscosity, which have not yet been studied, this condition is certainly satisfied

with an instrument of long period in the temperature-measuring circuit. Loss of heat in our work merely results in decreased efficiency and makes measurements a little more difficult ; it does not result in an inaccurate determination of a temperature change.

The effects of eddy currents can only be eliminated by making them very small. The quantity of heat liberated per unit volume in the whole specimen is given by $\frac{\sigma R^2}{8}\int\left(\frac{dB}{dt}\right)^2 dt$, where σ is the electrical conductivity, R the radius of the rod and dB/dt is the rate of change of induction. Adelsberger (1927) states that the above expression reduces to $\frac{\sigma R^2}{8}\ \frac{\Delta B^2}{t}$, where t is the interval of time in which a finite change ΔB in the induction takes place, but this is open to the criticism that the self-inductance of the specimen is ignored. Ellwood measured it by a cathode-ray oscillograph and showed that the effects in his work were very small. The best proof of their smallness lies in the fact that whether a cycle is described in n steps or in $2n$ steps the total hysteresis heat is exactly the same; this was always the case in our experiments to an accuracy of at least 1 per cent, except in the experiments on permalloy C.

Concerning the errors peculiar to our method, there must always be a stray field around the solenoid, but it is possible to place the core horizontal in a region where this field is small and fairly uniform, and the primary and secondary windings are so distributed that very little effect on the temperature-measuring instrument is possible. The centre of the core was placed about 130 cm. from the centre of the solenoid, and any residual effects were eliminated by disconnecting the thermocouples from the specimen and moving the transformer until no deflection resulted when a heavy current was reversed in the solenoid.

At first sight, it would appear that with a symmetrical distribution of the thermojunctions and their leads there should be no stray induction effects. However, the temperature-measuring instrument is so sensitive that a minute lack of symmetry can produce a very big deflection when the solenoid field is changed. Fortunately, the effects can be entirely eliminated, although the elimination is sometimes a very tedious process. The coil C shown in figure 4 was a compensating coil which was mounted on a brass rod so that it could be placed in an accurately determined position, with its plane horizontal. C was joined in series with a separate primary winding on the transformer, the total resistance of the coil and its winding being exactly equal to that of a single thermocouple circuit, so that there was no difference between the time factors of the compensating and the thermocouple circuits. The presence of an induction effect is manifested by sharp or jerky initial deflection of the temperature-measuring instrument, and, whereas the sign of the true thermal deflection is independent of the direction in which the hysteresis cycle is traversed, the sign of the former depends upon that direction. It is therefore easy to see when induction effects have been eliminated.

Unfortunately, there is no simple relation between a change in the solenoid current and the stray induction. Consequently, the latter has usually to be eliminated for each individual "step" in a proposed hysteresis cycle. This means that before taking a set of thermal measurements the correct position of the coil C must be found for each proposed step, so that it can be properly placed before each current change is made. These positions may sometimes all be found in a few minutes, but sometimes they take hours to complete, depending on the relation between I and H for the material in hand. In some cases, I changes fairly regularly with H, step by step; in others, large changes of I occur in the course of a few steps only. Changes in the solenoid current did not cause fluctuations in the temperature of the "cold" junctions, for when the specimen Ni was replaced by a brass rod of the same dimensions, no deflection resulted when large current variations were made.

§ 4. RESULTS

The measurements to date have been confined to nickel and nickel-iron alloys, because nickel can be obtained pure, and because the magnetic properties of nickel and certain nickel-iron alloys under tension are of theoretical interest. A typical set of thermal measurements and the magnetic data for one specimen are reproduced below.

In table 1 under dQ_1 are given the deflections obtained in traversing one-half of a cycle from $H = -192{\cdot}8$ to $H = +192{\cdot}8$ oersteds, and under dQ_2 the deflections in similarly traversing the other half of the cycle from $H = +192{\cdot}8$ to $H = -192{\cdot}8$, the values dQ_2 generally being used as a check, as the two halves of the cycle are symmetrical. The value of ΣdQ_1 obtained in traversing the half-cycle from $H = -192{\cdot}8$ to $H = +192{\cdot}8$ should be equal to $\int_{-192\cdot8}^{+192\cdot8} H dI$, so that a deflection of 4·04 cm. should correspond to 13,343 ergs per c.c., or 1 mm. deflection should correspond to 330·2 ergs per c.c. The close agreement between this value and the stated calibration value thus provides a proof of Warburg's law to within about 1 per cent. Hence, Warburg's law may be invoked for calibration purposes, and it seemed preferable to adopt this method as long as direct calibration did not depart from the magnetic determination by more than 1 per cent. The advantages are that the initial and final points on the thermal and the $\int H dI$ curves, described below, must coincide, and a precise knowledge of α is not necessary. This method is not satisfactory for measurements with the virgin magnetic state, when the calibration obtained by loading was always used.

The values of the coercivity, H_c, the initial susceptibility, k_0, the remanence, I_r, and the maximum intensity of magnetization, I_{max}, are given below; the values of k_0 are intended as a guide only.

Specimen No. I

Hard-drawn nickel (Sir Henry Wiggin and Co., Ltd.).

Chemical composition:—99·67 % Ni, 0·04 % C, 0·02 % Si, 0·04 % Cu, 0·08 % Fe, 0·01 % Mn, 0·14 % Mg.

Diameter, 0·474 cm.; H_c, 26·1 oersted; k_0, 3·9 e.m.u. per c.c.
Load during measurements, 0 kg. per mm.^{2}
Calibration load, 1877 gm.
Temperature at calibration, 283·7° K. I_{max}, 345·5 gauss; I_r, 250 gauss.
α, $12{\cdot}8 \times 10^{-6}$ deg.$^{-1}$ c.; (stated value for pure nickel) (Guillaume, 1919–20).
Calibration deflections:—Load on, 11·37 cm., 11·38 cm., 11·49 cm.
Load off, 11·46 cm., 11·43 cm., 11·44 cm.
Mean = 11·43 cm.
Sensitivity from calibration, 1 mm. deflection corresponds to 332 ergs per c.c.

Table 1. Magnetic and thermal data

Solenoid current (amperes)	H (oersteds)	I (gauss)	dQ_1 (cm.)	dQ_2 (cm.)	ΣdQ_1 (cm.)
−1·600	−192·8	−345·5	—	—	0·00
−1·280	−153·9	−338·7	−0·35	−0·36	−0·35
−0·884	−105·7	−327·0	−0·50	−0·50	−0·85
−0·650	−77·4	−317·3	−0·24	−0·24	−1·09
−0·439	−51·7	−305·1	−0·30	−0·30	−1·39
−0·233	−26·6	−284·1	−0·15	−0·15	−1·54
−0·003	0·97	−244·8	−0·21	−0·21	−1·75
0·003	1·7	−243·8	0·00	0·00	−1·75
0·190	23·7	−129·1	0·63	0·63	−1·12
0·200	24·7	−70·3	0·43	0·43	−0·69
0·221	26·7	52·9	0·98	0·98	0·29
0·280	32·7	242·5	1·71	1·72	2·00
0·439	51·7	294·8	0·60	0·60	2·60
0·650	77·4	315·0	0·40	0·40	3·00
0·884	105·7	326·8	0·30	0·30	3·30
1·280	153·9	338·7	0·42	0·42	3·72
1·600	192·8	345·5	0·32	0·33	4·04

$\int_{-192{\cdot}8}^{192{\cdot}8} H dI = 13{,}343$ ergs per c.c., obtained from the (I, H) graph.

Sensitivity from Warburg's law, 1 mm. corresponds to 330·2 ergs per c.c.

It is stated above that the load during measurements was 0 kg. per mm.^{2} This statement is not strictly correct, since the specimen is under its own weight and that of certain thermocouples, etc., which, however, compared with the loads deliberately applied in the following measurements, are very small.

The data of table 1 are plotted in figure 5, where the curve *abcd*, corresponding to the branch *a′b′c′d′* of the hysteresis cycle shown in that figure, is obtained by plotting the values of ΣdQ_1 against the corresponding values of H. The curve *defg* is obtained by adding the appropriate value of ΣdQ_2 to the final value of ΣdQ_1 for $H = +192{\cdot}8$ and plotting their sum against the corresponding value of H, so that *defg* corresponds to *d′e′f g′* of the hysteresis cycle. (In table 1 the values of dQ_2 should, of course, run from $H = +192{\cdot}8$ to $H = -192{\cdot}8$.) Some of the experimental points which would lie on the initial portion *de* of *defg* have been omitted from the figure, in order to avoid confusion. In order to save space in

the remaining figures, only the curves corresponding to *abcd* are plotted, since it is clear that those corresponding to *defg* can be obtained by rotating the curve *abcd* about the axis of ordinates and displacing it vertically until the starting point *a* coincides with the position originally occupied by the end-point *d*. The values of $\int_{192 \cdot 8}^{H} H dI$ are also plotted against I in figure 5, all values being

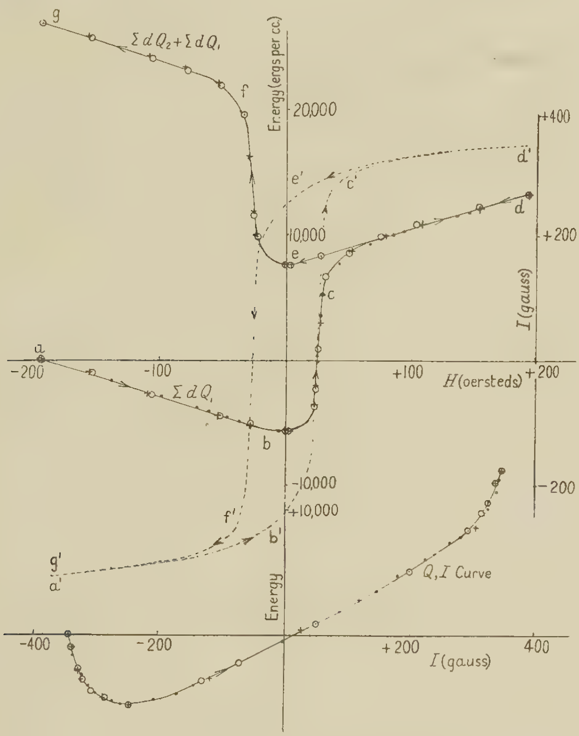


Figure 5. Hard-drawn nickel, specimen No. I, unloaded.

⊙ Q-measurements with solenoid on brass former. + Q-measurements with solenoid on micanite former.

◦ • Calculated values of $\int H dI$. - - - (I, H) curve.

The arrows show the direction in which the cycle was described, and the small letters indicate corresponding portions of the Q and hysteresis curves, the primed letters referring to the latter.

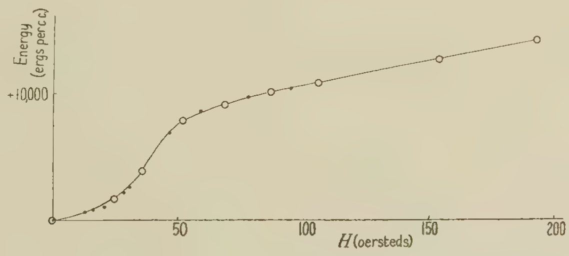


Figure 6. Hard-drawn nickel, specimen No I, unloaded. Virgin curve. (To avoid confusion the shape of the calculated $\int H dI$ is indicated by . . .) This is an exceptional case in which $\int H dI = \int dQ$.

expressed in ergs per c.c. Figure 6 gives the data for Q and $\int_0^H HdI$ against H for the virgin state, i.e. when we start with the specimen initially demagnetized by the method of reversals and magnetize it step by step.

Reference has been made to possible theoretical objections to the presence of metal other than the specimen and the solenoid winding. We therefore made a special solenoid, to give the same fields, wound with the same kind of wire, but upon a micanite tube instead of a brass former; while this does not avoid the presence of *all* other conductors, it represents a very substantial change in the experimental conditions. Zero drift was now very troublesome, but the thermal measurements on specimen I were repeated with the new solenoid. The results are represented by the crosses in figure 5, showing that within the limits of experimental error the presence of the brass former made no difference.

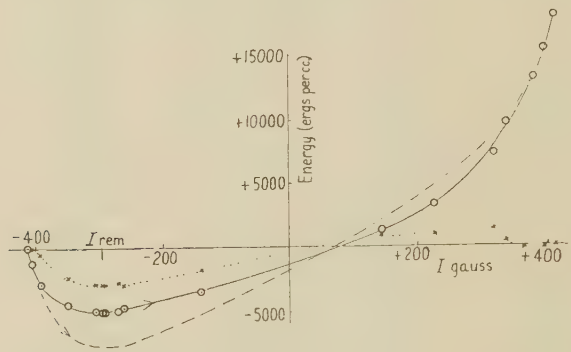


Figure 7. Hard-drawn nickel, specimen No. II, unloaded.
——— Q, I. - - - - - - $\int HdI, I$ . . . . . . $\int HdI - Q, I$.

Hardy and Quimby (1938) were the first workers to appreciate the importance of plotting the thermal data and $\int HdI$ against I, since internal-energy, including magnetostriction, changes are more adequately envisaged in terms of I. Throughout the present work the results were always plotted against H and I, and the various examples given here show that the two modes of plotting bring out features which might be overlooked if only one mode were used. It is emphasized that while magnetic and thermal measurements were always made over the complete hysteresis cycle, the results for one branch only are plotted in all figures, except figure 5, in order to save space. The importance of plotting $\int HdI - Q$ against I does not appear to have been realized by most of the earlier workers.

Specimen No. II

Hard-drawn nickel (Sir Henry Wiggin and Co., Ltd.).

Chemical composition, 99·98% pure nickel with less than 0·001% S, less than 0·02% C, with a trace only of other impurities.

Diameter, 0·476 cm.; H_c, 26·5 oersteds; $k_0 = 1{\cdot}14$ e.m.u. per c.c.

Load during measurements, 0 kg. per mm.^{2}

Temperature at calibration, 283·6° K.

Sensitivity from calibration, 1 mm. corresponds to 314 ergs per c.c.

Sensitivity from Warburg's law, 1 mm. corresponds to 311 ergs per c.c.

$\int_{-193\cdot 8}^{193\cdot 8} HdI = 18{,}168$ ergs per c.c.; I_{max}, 413 gauss; I_r, 293 gauss.

The values of Q, $\int HdI$ and $\int HdI - Q$ for the cycle are shown in figure 7.

Specimen No. III

Hard-drawn nickel (Adam Hilger and Co., Ltd.).

Chemical composition:—99·53% Ni, 0·19% Mg, 0·05% Cu, 0·011% Mn, 0·14% Fe, 0·023% Si, 0·029% C, 0·01% Cr, 0·003% Al, 0·004% Cu, 0·008% Pb, with very slight traces of Sn and Zn.

(Cat. No. F, 214.) These rods were not available in the required length of 40 cm. Two rods 15 cm. long were joined, by drilling and tapping two adjacent ends, making a specimen 29·5 cm. long, for which the demagnetization factor was somewhat larger than usual.

Diameter, 0·500 cm.; H_c, 26·9 oersteds; k_0, 1·68 e.m.u. per c.c.

Load during measurements, 0 kg. per mm^2.

Temperature at calibration, 288·9° K.

Sensitivity from calibration, 1 mm. corresponds to 305 ergs per c.c.

Sensitivity from Warburg's law, 1 mm. corresponds to 305 ergs per c.c.

$\int_{-188\cdot 8}^{+188\cdot 8} HdI = 17{,}449$ ergs per c.c.; I_{max}, 412 gauss; I_r, 278 gauss.

There was no significant difference between the results for specimens II and III. Small, and somewhat irregular, values of $\int HdI - Q$ are characteristic of specimens of hard-drawn nickel.

§5. Effects of annealing

In order to study the effects of annealing the above hard-drawn specimens, they were annealed as described below and the following data obtained:—

Specimen No. I A

Chemical composition identical with that of specimen I.

Details of annealing process—Heated at 870° C. for 1 hour *in vacuo* and cooled slowly (110 to 120° C. per hour).

H_c, 4·5 oersteds; k_0, 4·25 e.m.u. per c.c.

Load during measurements, 0 kg. per mm^2.

Sensitivity from calibration, 1 mm. corresponds to 339 ergs per c.c.

Sensitivity from Warburg's law, 1 mm. corresponds to 342 ergs per c.c.

$\int_{-192\cdot 4}^{+192\cdot 4} HdI = 3196$ ergs per c.c.; I_{max}, 427 gauss; I_r, 213 gauss.

Results are shown in figures 8 and 9. The $\left(\int HdI - Q,\ I\right)$ curves closely

resembled those of figures 14 and 15. The large negative values of $\int HdI - Q$ and smooth $(\int HdI - Q, I)$ curves are characteristic of annealed nickel.

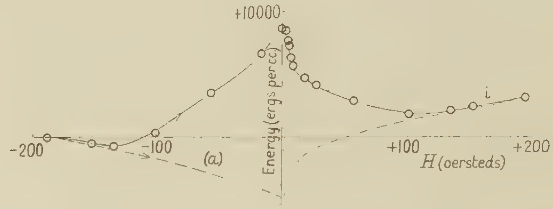


Figure 8. Annealed nickel, specimen No. I A, unloaded.
——— Q, H. - - - $\int HdI, H$.

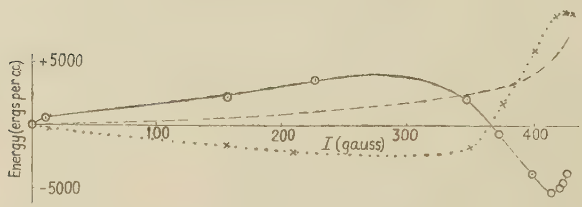


Figure 9. Annealed nickel, specimen No. I A, unloaded. Virgin curve.
——— Q, I. - - - $\int HdI, I$. ..... $\int HdI - Q, I$.

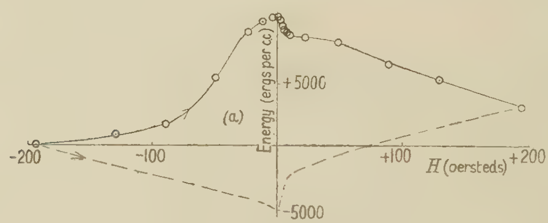


Figure 10. Annealed nickel, specimen No. II, unloaded.
——— Q, H. - - - $\int HdI, H$.

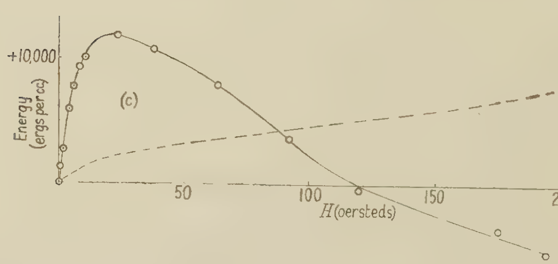


Figure 11. Annealed nickel, specimen No. II, unloaded. Virgin curve.
——— Q, H. - - - $\int HdI, H$

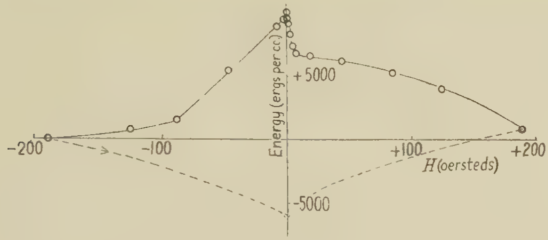


Figure 12. Annealed nickel, specimen No. III, unloaded.
—— Q, H. - - - $\int HdI, H$.

Specimen No. II

Details of annealing process:—Heated to 1100° c. for $\frac{1}{2}$ hour *in vacuo* and cooled slowly.

H_c, 3·1 oersteds; k_0, 21·8 e.m.u. per c.c.

Load during measurements, 0 kg. per mm.²

Sensitivity from calibration, 1 mm. corresponds to 354 ergs per c.c.

Sensitivity from Warburg's law, 1 mm. corresponds to 349 ergs per c.c.

$\int_{-194\cdot8}^{+194\cdot8} HdI = 3104$ ergs per c.c.; I_{max}, 426 gauss; I_r, 268 gauss.

Results are shown in figures 10 and 11. The $(\int HdI - Q, I)$ curves were smooth and characteristic of annealed nickel, *vide* specimen No. IV, below.

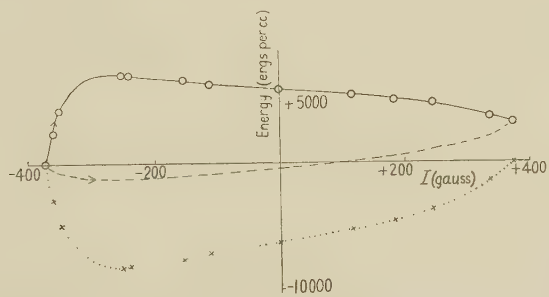


Figure 13. Annealed nickel, specimen No. IV, unloaded. Maximum field, 46·7 oersteds.
———— Q, I. - - - $\int HdI, I$. ...... $\int HdI - Q, I$.

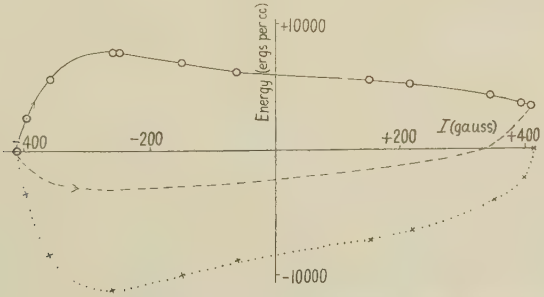


Figure 14. Annealed nickel, specimen No. IV, unloaded. Maximum field, 100 oersteds.
———— Q, I. - - - $\int HdI, I$. ..... $\int HdI - Q, I$.

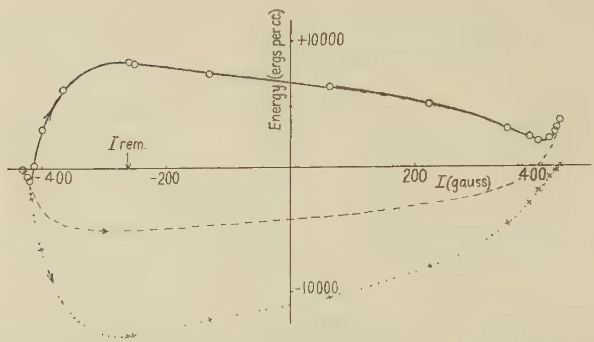


Figure 15. Annealed nickel, specimen No. IV, unloaded. Maximum field 192·4 oersteds.
——— Q, I. --- $\int HdI, I$. ...... $\int - Q, I$.

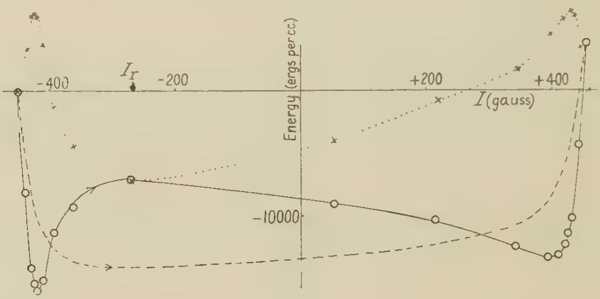


Figure 16. Annealed nickel, specimen No. IV, unloaded. Maximum field 411·3 oersteds.
——— Q, I. --- $\int HdI, I$. .... $\int HdI - Q, I$.

Specimen No. III

Details of annealing process:—Heated to 1100° c. for 1 hour *in vacuo* and cooled slowly.

H_c, 1·6 oersteds; k_0, 19·6 e.m.u. per c.c.

Load during measurements, 0 kg. per mm.²

Sensitivity from calibration, 1 mm. corresponds to 347 ergs per c.c.

Sensitivity from Warburg's law, 1 mm. corresponds to 350 ergs per c.c.

$\int_{-189\cdot5}^{+189\cdot5} HdI = 903$ ergs per c.c.; I_{max}, 440 gauss.

Results are shown in figure 12.

Specimen No. IV

This specimen had the same chemical composition as specimen No. II, and was specially annealed for us by Dr. L. B. Pfeil. The annealing process, which is that found most satisfactory for high purity nickel, consisted in heating the rod rapidly to a temperature of 900° c. within about 2 minutes, and quenching it in water immediately this temperature was reached. The grain size produced by this treatment is finer the greater the degree of cold-reduction applied. The specimen was extremely soft and had to be handled with care. The results are

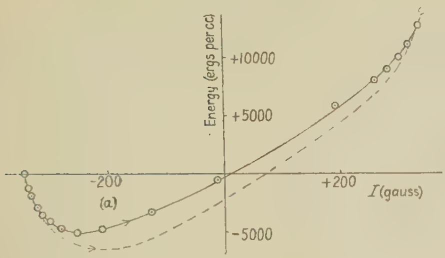


Figure 17 *a*. Hard-drawn nickel, specimen No. I. Load 1·70 kg. per mm².
——— Q, I. - - - - $\int HdI, I$.

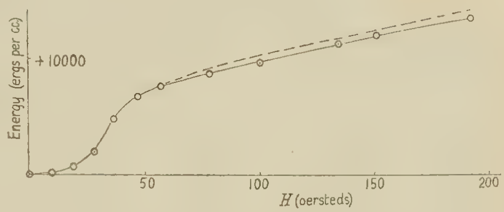


Figure 17 *b*. Hard-drawn nickel, specimen No. I. Virgin curve. Load 1·70 kg. per mm².
——— Q, H. - - - $\int HdI, H$.

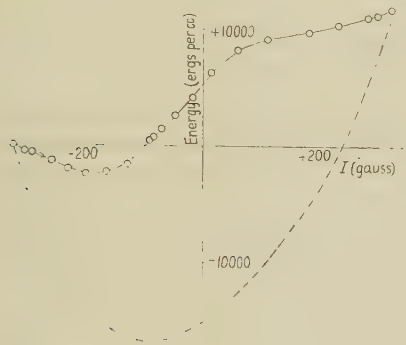


Figure 18. Hard-drawn nickel, specimen No I. Load 8·67 kg. per mm².
——— Q, I. - - - - $\int HdI, I$.

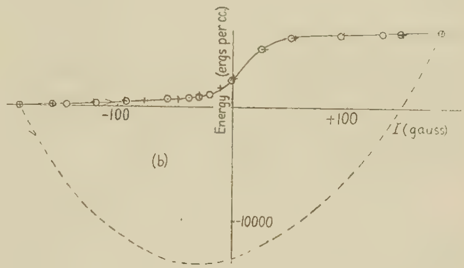


Figure 19. Hard-drawn nickel, specimen No. I. Load 21·4 kg. per mm².
——— Q, I. - - - $\int HdI, I$.

given in the third line of table 2 and in figure 15; they do not depart appreciably from those depicted in figure 8 for the same maximum field.

§ 6. EFFECTS OF FIELD RANGE

Experiments were made with specimen No. IV, unloaded, to determine the thermal changes accompanying the traversal of hysteresis cycles with the different maximum fields stated in table 2; the graphs are plotted as functions of I only. S_1 gives the sensitivity from calibration and S_2 that deduced from Warburg's law.

Table 2

Maximum field H (oersteds)	I_{max} (gauss)	S_1 ergs/c.c. per mm.	S_2 ergs/c.c. per mm.	$\int_{-H}^{+H} HdI$ (ergs per c.c.)	Coercivity (oersteds)	Relevant figures
46·7	374	335	330	3279	3·92	13
100·0	413	335	333	3541	4·03	14
192·4	429	335	333	3766	4·18	15
411.3	455	330	330	3881	4·31	16

§7. EFFECTS OF LOADING

Hard-drawn nickel

Specimen No. I was used throughout, and the data obtained are recorded in table 3.

Table 3

Load (kg. per mm²)	S_1 (ergs/c.c. per mm.)	S_2 (ergs/c.c. per mm.)	Maximum field H (oersteds)	$\int_{-H}^{+H} HdI$ (ergs per c.c.)	Coercivity (oersteds)	I_{max} (gauss)	Relevant figures
0	332	330	192·8	13,343	26·1	345·5	5 and 6
1·70	320	320	192·7	14,179	29·6	344·6	17
3·72	324	325	192·9	12,503	30·9	342·6	
5·28	331	331	193·0	13,574	33·7	339·6	
8·67	332	330	193·0	11,909	34·6	325·0	18
12·1	331	330	193·1	10,798	33·3	290·2	
21·4	331	331	193·7	6,651	30·0	185·3	19 (circles)
21·4*	331	336	193·7	6,651	30·0	185·3	19 (crosses)
31·2	333	330	193·9	2,752	19·8	126·0	

* These data were obtained with the solenoid wound on micanite.

Annealed nickel

Specimen No. I A was used throughout, and the data obtained are recorded in table 4.

Table 4

Load (kg. per mm²)	S_1 (ergs/c.c. per mm.)	S_2 (ergs/c.c. per mm.)	Maximum field H (oersteds)	$\int_{-H}^{+H} HdI$ (ergs per c.c.)	Coercivity (oersteds)	I_{max} (gauss)	Relevant figures
0	339	342	192·4	3,196	4·5	427·0	8 and 9
1·70	338	341	192·5	3,142	5·2	386·3	20
3·99	327	333	192·5	2,561	6·0	377·2	
5·33	333	330	192·6	2,841	7·5	364·9	21
8·75†	335	332	192·6	2,275	9·3	360·0	22
12·3	335	340	193·1	3,381	15·4	261·5	
18·7	330	333	193·6	3,583	21·2	177·5	
26·2	330	335	193·8	3,109	20·9	142·0	
33·0	330	333	194·2	2,624	20·9	120·0	23

† Specimen showed permanent changes in cross-section when this load was applied; these attained 9·3 per cent of the initial area when under the maximum load of 33·0 kg. per sq. mm.

§8. EFFECTS OF CIRCULAR MAGNETIZATION

According to modern theory, in a heavily stressed nickel rod the magnetic vectors set perpendicular to the axis of the rod in the absence of an applied field. The rod is, of course, unmagnetized, and we have no knowledge of the way in which the vectors are arranged. For example, they might be arranged radially or in any random manner which gives zero magnetic effect externally. If, however, a heavy current is passed through the rod, the latter should be circularly magnetized, so that, on the application of a longitudinal field all the vectors should tend to

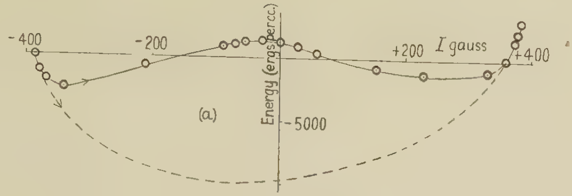


Figure 20 *a*. Annealed nickel, specimen No. I A. Load 1·70 kg. per mm².

———— *Q*, *I*. - - - $\int HdI$, *I*.

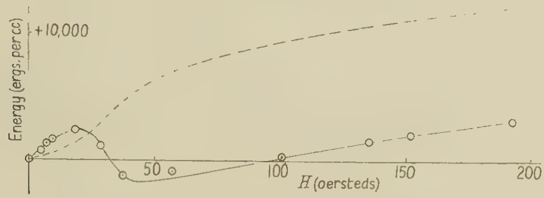


Figure 20 *b*. Annealed nickel, specimen No. I A. Virgin curve. Load 1·70 kg. per mm².

———— *Q*, *H*. - - - $\int HdI$, *H*

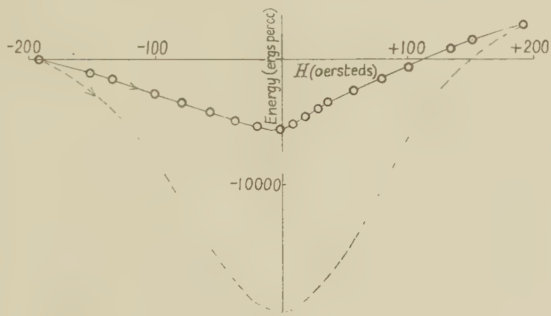


Figure 21. Annealed nickel, specimen No. I A. Load 5·33 kg. per mm².

———— *Q*, *H*. - - - $\int HdI$, *H*.

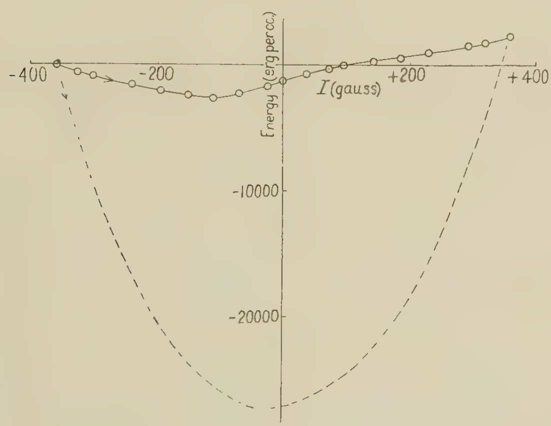


Figure 22. Annealed nickel, specimen No. I A. Load 8·75 kg. per mm².

———— *Q*, *I*. - - - $\int HdI$, *I*.

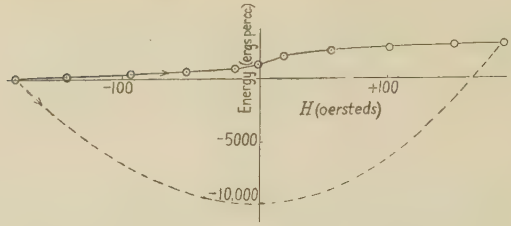


Figure 23. Annealed nickel, specimen No. I A. Load 33·0 kg. per mm².
—— Q, H. - - - $\int HdI, H$.

rotate in the same manner. A current of about 5 amperes was passed through specimen No. I A for a short time while it was under a stress of 33 kg. per mm². It was found on taking the specimen through a half-cycle from $H = -200$ to $H = +200$ that there was no noteworthy departure from the results already given in figure 23.

§ 9. EXPERIMENTS WITH ALLOYS

The experiments on nickel-iron alloys have been limited to a few chosen on account of their special magnetic or magnetostrictive characteristics. The chemical constitutions of specimens Nos. V, VI and VII, kindly supplied by Sir Henry Wiggin and Co., Ltd., are given in table 5. Nickel-iron alloys are not malleable even in the purest form at present available, so that it is usual to add a small quantity of magnesium or other metal to combine with any unwanted impurities present and to remove oxygen and, possibly, other gases.

Table 5

Specimen	No. V	No. VI	No. VII
Carbon	0·04	0·03	0·04
Silicon	0·06	0·06	0·12
Copper	0·17	0·16	0·13
Manganese	0·37	0·38	0·42
Nickel	48·64	41·90	36·28
Iron	50·72	57·47	63·01

All the rods were 0·476 cm. in diameter and all were investigated when unloaded, and also when under the severe tension of 30·0 kg. per mm². The results are given in table 6.

Table 6

Specimen No.	Load (kg. per mm²)	S_1 (ergs/c.c. per mm.)	S_2 (ergs/c.c. per mm.)	Maximum field H (oersteds)	I max (gauss)	$\int_{-H}^{+H} HdI$ (ergs per c.c.)	Relevant figures
V	0	332	330	189·2	988	4,386	24
	30·0	328	333	189·4	977	4,227	
VI	0	319	318	189·4	967	2,226	
	30·0	320	320	189·5	950	3,303	
VII	0		307	189·6	933	2,549	25
	30·0		330	190·0	882	3,088	

In the case of specimen No. VII there is so much uncertainty concerning the value of α that calibration was based entirely upon Warburg's law. This specimen approximates in constitution to that of Invar, which is described as a 36 per cent nickel steel. Our measurements on Invar were recently reported elsewhere (Bates and Weston, 1940).

In view of their commercial importance and special theoretical interest, we made experiments with mu-metal rod supplied by Messrs. Telegraph Construction and Maintenance Co., Ltd., and with permalloy C supplied by Messrs. Standard Telephones and Cables, Ltd. It is unfortunate that the experiments were exceedingly difficult owing to the small hysteresis losses, 130 ergs per c.c. per half-cycle in the mu-metal experiments and about 30 only in the permalloy experiments.

The relevant curves for a mu-metal rod, specimen No. VIII, 0·400 cm. in diameter, are given in figure 26, where the broken curve represents the behaviour of $\int_{-193\cdot 1}^{H} H dI$ with H for the unloaded rod, and the other curves represent the thermal measurements with the several tensions in kg. per mm.^{2} denoted by the numerals on them. The thermal data do not compare in accuracy with the data for other specimens, the energy scale of figure 26 being five times that of earlier figures; large field steps were necessary in order to obtain readable deflections. There is in our view, however, no doubt that under severe stress very large field changes are unaccompanied by measurable changes in temperature of the specimen, with saturation values of I. The length of the specimen increased by about 18 per cent under the maximum load.

The relevant curves for the experiments with a permalloy C rod, specimen No. IX, are given in figure 27. Owing to the small thermal changes, accompanied by eddy currents which it was impossible to eliminate by experimental means, we did not consider it worth while to examine the specimen under load, and our measurements are calibrated by loading, α being found equal to $11 \cdot 8 \times 10^{-6}$ deg.$^{-1}$ C. in a determination by an ordinary laboratory method. The observed and the calculated hysteresis losses did not agree, and we considered that the excess of the former over the latter was due to eddy-current effects. This excess was assumed to be directly proportional to $(\Sigma dB)^2$, where dB is the change in induction for an individual field change, and the eddy-current effect $d\epsilon$ for any individual step dB was likewise assumed proportional to dB^2. On subtracting $\Sigma d\epsilon$ from ΣdQ_1, results were obtained which were taken to be free from eddy-current disturbances; these are shown by the encircled points in figure 27.

§ 10. DISCUSSION OF RESULTS

A striking feature of the results is the accurate confirmation of Warburg's law, which is effectively demonstrated by comparing the values ΣS_1 and ΣS_2 obtained by adding the values of S_1 and S_2 in tables 2, 3, 4 and 6 whenever independent values of both S_1 and S_2 are given for loaded and unloaded specimens.

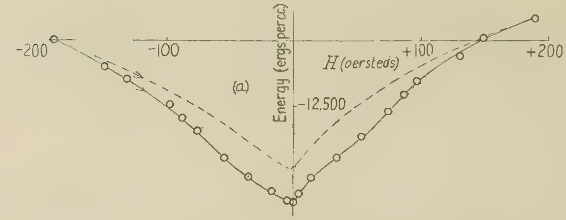


Figure 24. 48·6 per cent nickel-iron alloy, unloaded.
——— Q, H. - - - $\int HdI, I$.

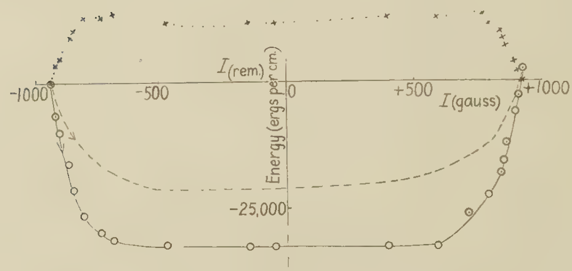


Figure 25. 36·3 per cent nickel-iron, unloaded.
——— Q, I. - - - $\int HdI, I$. . . . . . . $\int HdI-Q, I$.

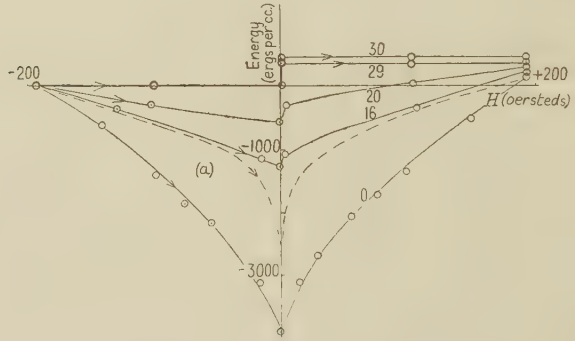


Figure 26. Mu-metal under various loads. The numerals represent the several loads in kg. per mm.[2]
——— Q, H. - - - $\int HdI, H$ curve for unloaded specimen.

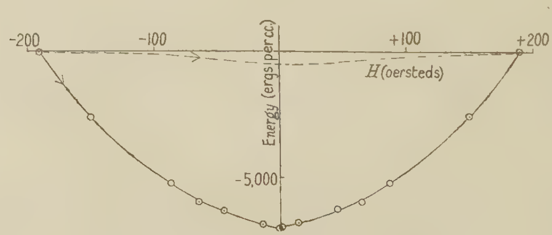


Figure 27. Permalloy C, unloaded.
——— Q, H. - - - $\int HdI, H$.

It is found that $\Sigma S_1 = 8596$ and $\Sigma S_2 = 8609$. This satisfactory agreement is, of course, dependent upon the values taken for the coefficients of expansion, but appreciable error in these values is unlikely.

We have succeeded in reproducing, in one way or another, every type of curve obtained by previous workers. For example, figures 5 and 7 for unloaded hard-drawn nickel are similar to those obtained by Miss Townsend. Both Miss Townsend and Hardy and Quimby found rather greater initial cooling with hard-drawn nickel than that shown in our figures, but their nickel was only 99·44 per cent pure, containing as much as 0·18 per cent iron, and it is significant that with nickel-iron alloys we always find very pronounced cooling, *vide* figures 24 and 25. Hardy and Quimby also used annealed nickel 99·44 per cent pure, and their results are similar to those of figure 16, except that the deep troughs occur at higher values of I, obtained in much smaller fields, presumably because their mode of annealing and the composition gave a much lower coercivity.

It is difficult at the present time to discuss more than a few features which are shown by an admittedly incomplete analysis of the measurements, which we hope to extend when opportunity can be found. We first note that in the case of hard-drawn nickel the curves for unloaded specimens are all of the same general shape, and that the known small differences in purity of the several specimens appear to have little influence on the thermal measurements. There is in figures 5 and 6 a remarkable and most unexpected coincidence of the Q curves obtained from thermal measurements and the $\int H dI$ curves calculated from the magnetic measurements with specimen No. I. Using the method of analysis set forth in equation (1 *a*) we may make a detailed examination of the energy changes over all portions of the hysteresis cycles. It is found that, apart from the exceptional case of specimen No. I, when magnetization of an unloaded nickel specimen is increased $(dE/dI)_T$ is negative whenever the magnetization processes are magnetically reversible and positive whenever they are magnetically irreversible.

It is generally accepted that, in the initial stages, magnetization proceeds from the virgin state mainly by the growth of Weiss domains whose magnetic vectors are favourably aligned with respect to an applied magnetic field, at the expense of their neighbours whose vectors are less well aligned. Two distinct kinds of boundary displacement may therefore be visualized; first, one in which the magnetic vectors of the adjacent domains are at right angles to one another, and, second, one in which the vectors are antiparallel, i.e., oppositely directed. These are termed, respectively, 90° and 180° boundary displacements. The former are magnetically reversible and begin in an infinitely small field, while the latter are usually irreversible in all but the softest materials and require a definite limiting field to start them. The later stages of magnetization in high fields consist in the rotation of the magnetic vectors from their directions of easy magnetization (the [111] direction in the case of nickel) to the direction of the applied field; such rotations are more or less magnetically reversible.

Turning to figure 9, for annealed nickel we see that for the initial 90° boundary

displacements $(dE/dI)_T$ is negative, but, when in higher fields the 180° displacements are preponderant, $(dE/dI)_T$ is positive, and it finally becomes zero and then negative when the region of rotations is reached. Similarly, in the case of the initial magnetization of hard-drawn nickel, $(dE/dI)_T$ becomes zero for a value of I just below the knee of the (I, H) curve and becomes strongly positive at higher field values.

In discussing the course of $(dE/dI)_T$ with increase in I in any half-cycle, it is best to start at $I=I_r$ and examine what occurs as the field is increased from zero to its maximum positive value. Thus, for the annealed specimen of figure 15 $(dE/dI)_T$ is zero at $I=I_r$, i.e., when the 180° boundary displacements commence to be effective. Thereafter, it is positive over the remaining field range, which is not sufficient to allow rotations to be important. In figure 16, for the same specimen, the range of field is twice as great and rotations become important at the higher values, giving rise to marked negative values of $(dE/dI)_T$. In the same way, for the hard-drawn nickel specimen of figure 7, $(dE/dI)_T$ is zero at $I=I_r$ and takes positive values until values of I above the knee of the (I, H) curve are reached, when it becomes negative.

There is an interesting correlation between the minimum value of $\int HdI-Q$, i.e. the lowest value reached at $I=I_r$, and the coercive force; this is shown by the data in table 7.

Table 7.

Specimen No.	H_c (oersteds)	Minimum value $\int HdI-Q$ (ergs per c.c.)	Maximum range of $\int HdI-Q$, on virgin curve (ergs per c.c.)
I	26·1	0	0
II (hard)	26·5	−2,860	+5,400
III (hard)	26·9	−2,200	+7,040
I A	4·5	−13,400	+11,600
IV*	4·31	−13,500*	—
IV	4·18	−13,500	—
II (annealed)	3·1	−15,300	+22,800
III (annealed)	1·6	−17,000	+18,100

It is reasonable to suppose in the cases recorded in the table, with the exception of that marked with an asterisk, that practically all the boundary extensions are complete, and few rotations have occurred when the specimens are magnetized to the maximum extent in fields of about 200 oersteds. In the case of the data marked with an asterisk the minimum value of $\int HdI-Q$ was obtained by taking the difference between the positive peak on the left-hand side of figure 16 and the negative minimum at $I=I_r$.

It is obvious from the table that the lower the coercivity the more pronounced is the minimum value of $\int HdI-Q$. There is a similar correlation between the maximum range of $\int HdI-Q$, i.e., the difference between the minimum and the end value of this quantity, in the case of the virgin curves. The latter correlation is, however, not quite as clear-cut as the former, presumably because the magnetic

energy in the end state is not the same as that in the beginning. The energy differences in columns 3 and 4 of the table are, with appropriate sign, measures of the energy changes associated with the 180° boundary displacements and are important in a theoretical discussion of the magnetostrictive properties of unloaded specimens.

The virgin curves for the nickel-iron alloys so far studied show that in the initial stages $(dE/dI)_T$ is always zero or slightly negative, and that it becomes much more strongly negative at high values of I, in marked contrast to the behaviour of pure nickel. The results for magnetization cycles, as in figure 25, show that $\int HdI - Q$ is always positive, $(dE/dI)_T$ being practically zero around $I = I_r$, and over a wide range of I values, after which it becomes very strongly negative. The low value of $(dE/dI)_T$ is consistent with the fact that the alloy is hard-drawn and that when I is small very large changes in magnetization are due to boundary displacements which require comparatively little energy, while the high negative values are due to magnetically reversible rotations which require much more.

The method of analysis of equation (1) is not adequate for the examination of the results with loaded specimens. If we confine attention to reversible phenomena we may write

$$dU = T\,.\,dS + H\,.\,dI + F\,.\,dl, \qquad \ldots\ldots(4)$$

where F is the load expressed in dynes per unit area, and dl is the extension per unit length of the specimen. Taking S, H and F as three independent variables, it is readily shown that

$$\left(\frac{\partial H}{\partial T}\right)_{S,\,F} = \frac{-T}{J\rho C_{F,\,H}}\left(\frac{\partial I}{\partial T}\right)_{F,\,H}, \qquad \ldots\ldots(5)$$

$$\left(\frac{\partial T}{\partial F}\right)_{H,\,S} = \frac{-T}{J\rho C_{F,\,H}}\left(\frac{\partial l}{\partial T}\right)_{F,\,H} \qquad \ldots\ldots(6)$$

and

$$\left(\frac{\partial l}{\partial H}\right)_{S,\,F} = \left(\frac{\partial I}{\partial F}\right)_{H,\,S}. \qquad \ldots\ldots(7)$$

where $C_{F,\,H}$ is the specific heat of the material under constant load F and constant field H, and the other symbols have their usual meanings.

Equation (5) is the familiar statement for the magnetocaloric effect when $F = 0$, and shows that an increase ΔH in the applied field is accompanied by a change ΔT in the temperature, given by

$$\Delta T = \frac{-T}{J\rho C_{F\,H,}}\left(\frac{\partial I}{\partial T}\right)_H \Delta H.$$

When I approaches the saturation value $(\partial I/\partial T)$ is negative, so that ΔT is positive for positive increments in the field, but for low intensities $(\partial I/\partial T)_H$ is positive. The kinks for large values of I in figures 8, 15 and 16 are readily explained on the basis of negative values of $(\partial I/\partial T)_H$ in these regions. It might have been interesting to extend the experiments to still higher fields, but the highest fields were more than sufficient to turn the magnetic vectors in unloaded nickel from the [111]

direction of easy magnetization to the [100] direction of difficult magnetization, so that all the important regions of single-crystal phenomena were covered.

In the case of severely loaded nickel specimens, the magnetization processes are more simple and magnetic hysteresis losses are much reduced. The magnetic vectors are all perpendicular to the axis of the specimen in the absence of an applied field, and we have direct experimental evidence (Kirchner, 1936) that the longitudinal magnetostrictive changes of length are proportional to I^2. This evidence, together with that of Engler (1937) and Siegel and Quimby (1936), permits us to consider the length of the specimen as decided by the value of I^2 alone. Confining attention, as before, to reversible processes only, we may substitute $H=k_1 I$ and $(l-l_0)=k_2 I^2$, whence $dl=2k_2 I dI$, where dl is the change in length which accompanies a change dI in longitudinal magnetization. Substituting in equation (4), it follows that

$$\frac{\partial}{\partial S}\left\{-\left(\frac{k_1+2Fk_2}{k_1}\right)I\right\}_{H,\,F}=\left(\frac{\partial T}{\partial H}\right)_{S,\,F},$$

and, therefore, the adiabatic change in temperature ΔT for a field change ΔH is given by

$$\Delta T=\frac{-T}{J\rho C_{F,\,H}}\left(\frac{k_1+2Fk_2}{k_1}\right)\left(\frac{\partial I}{\partial T}\right)_H.\Delta H.$$

Now Becker has shown that for initial magnetization processes

$$k_1=\frac{3F\lambda_s}{I_s^2}\quad\text{and}\quad k_2=-\frac{3}{2}\frac{\lambda_s}{I_s^2},$$

where λ_s is the change in length per unit length of the specimen when the magnetization is changed from zero to the saturation value I_s. Consequently, (k_1+2Fk_2) is equal to zero under these circumstances. In other words, no reversible changes in temperature should accompany changes in magnetization of nickel under severe load. Our experiments show this to be the case, for there is no trace of cooling in figures 19 and 23. This behaviour is only to be expected when I varies linearly with H and when the magnetostriction varies linearly with I^2; the present experiments show that the first condition is reasonably satisfied with $F=10$ kg. per mm^2, while Kirchner has shown that the second condition is also fulfilled under the same load. Actually we found traces of reversible heating and cooling with specimens under a load of 8·57 kg. per mm^2, but there was no cooling at 12·2 kg. per mm^2 If, then, magnetization of a severely loaded specimen occurs only by rotation of the domain vectors, such rotation must be accompanied by frictional losses.

The outstanding feature of all our experiments on nickel iron alloys showing positive magnetostriction is that without exception the cooling changes observed during an incomplete cycle are always much greater than those given by $\int H dI$. In most cases both the magnitude of the cooling, and the difference between the thermal results and the calculated $\int H dI$ values, are increased by the application

of tension. The slope of the thermal curves of Q against H from $H = -200$ to $H = 0$ is approximately constant for each alloy.

It is interesting that there is no essential difference between the thermal behaviour in these experiments of unloaded mu-metal or permalloy C, which show extremely small magnetostriction effects, and that of unloaded 42% nickel-iron alloy which has a volume magnetostriction (Masiyama, 1931) some ten times greater than that of pure iron and some sixty times greater than that of pure nickel. There is, however, an outstanding difference in the case of severely loaded specimens, for, as figure 26 shows, in the case of severely loaded mu-metal the initial cooling disappears, i.e. $(\partial I/\partial T)_{S,F}$ becomes extremely small from $H = -200$ to $H = 0$, and there remains only the sudden evolution of heat within the small range of field values wherein reversal of magnetization takes place. Now, the magnetic changes in permalloy under load, apart from the suddén reversal of the sign of the magnetization at low field values, are reversible. Preisach (1932) has endeavoured to explain this feature by postulating the formation of demagnetization nuclei along these reversible portions of the magnetization curve. This would mean that we ought to observe reversible absorption and evolution of heat along the corresponding parts of the thermal curves of mu-metal and permalloy, but no evidence of this is found.

§ 11. ACKNOWLEDGEMENTS

We wish to express our thanks to Mr. G. G. Taylor for his help in early tests with the method, to Messrs. Johnson and Matthey for the gift of the fine silver strip, to Messrs. Standard Telephones and Cables, Ltd. for the gift of permalloy C rods, to Messrs. Telegraph Construction and Maintenance Co., Ltd. for the supply of selected mu-metal spiral cores, and to Dr. L. B. Pfeil, of the Mond Nickel Company Research and Development Department, who provided specimens of pure nickel and nickel-iron alloys, together with details of their composition and preparation. One of us (J. C. W.) is indebted to the Department of Scientific and Industrial Research for a Maintenance Allowance and to University College, Nottingham, for a Research Scholarship. Much of the apparatus used in this work was purchased from a grant to one of us (L. F. B.) by the Government Grant Committee of the Royal Society.

REFERENCES

Adelsberger, U., 1927. *Ann. Phys., Lpz.*, **83**, 184.
Bates, L. F., 1939. *Modern Magnetism* (Cambridge), p. 62.
Bates, L. F. and Weston, J. C., 1940. *Nature, Lond.*, **145**, 551.
Becker, R. and Döring, W., 1939. *Ferromagnetismus* (Springer), p. 53.
Bitter, F., 1937. *Introduction to Ferromagnetism* (McGraw-Hill), p. 14.
Constant, F. W., 1928. *Phys. Rev.* **32**, 486.
Ellwood, W. B., 1929. *Nature, Lond.*, **123**, 797; 1930. *Phys. Rev.* **36**, 1066.
Engler, O., 1937. *Ann. Phys., Lpz.*, **31**, 145.
Guggenheim, E. A., 1936. *Proc. Roy. Soc.* A, **155**, 49.
Guillaume, C., 1920. *Proc. Phys. Soc.* **32**, 374.

HARDY, T. C. and QUIMBY, L., 1938. *Phys. Rev.* **54**, 217.
HONDA, K., ÔKUBO, J. and HIRONÉ, T., 1929. *Sci. Rep. Tôhoku Univ.* **18**, 409.
JOULE, J. P., 1884. *Collected Works* (London: Phys. Soc.), **1**, p. 426.
KIRCHNER, H., 1936. *Ann. Phys., Lpz.*, **27**, 49.
MASIYAMA, Y., 1931. *Sci. Rep. Tôhoku Univ.* **20**, 574.
OKAMURA, T., 1936. *Sci. Rep. Tôhoku Univ.* **24**, 744.
PREISACH, F., 1932. *Phys. Z.* **33**, 913.
SIEGEL S. and QUIMBY, S. L., 1936. *Phys. Rev.* **49**, 663.
STONER, E. C., 1937. *Phil. Mag.* **23**, 833.
TOWNSEND, AGNES, 1935. *Phys. Rev.* **47**, 306.
WARBURG, E., 1881. *Ann. Phys., Lpz.*, **13**, 141.

VIBRATIONS OF FREE PLATES: ISOSCELES RIGHT-ANGLED TRIANGLES

By MARY D. WALLER, B.Sc., F.Inst.P.,
London (R.F.H.) School of Medicine for Women

Received 29 *July* 1940

ABSTRACT. The paper describes the results of systematic observations made on the vibrating modes of a free plate which is in the shape of a right-angled isosceles triangle. Any mode of vibration which is possible to this plate corresponds to some natural mode of the square plate, but the converse statement is only true in a restricted number of cases. Thus the only nodal systems of the square plate which have their counterpart on the triangular plate are given by $\omega = u_m(x)u_n(y) + u_n(x)u_m(y) = 0$. The triangular nodal systems differ markedly from the figures which are obtained by cutting the square nodal systems in halves diagonally; the natural frequencies of the triangular plate are appreciably lower than the corresponding frequencies of the square plate, these differences being caused by the changed boundary conditions.

§1. INTRODUCTION

Chladni (1802) expected that the nodal systems of a plate which is in the shape of a right-angled isosceles triangle would resemble the figures which are obtained by cutting the nodal systems of a square plate in halves diagonally. He found that they were very different. Such differences must be ascribed to the fact that the diagonal of the square becomes a free edge for the triangle.

There appear to be no records of either the nodal systems or natural frequencies of the right-angled triangular plate. As a comprehensive experimental study of the vibrating square plate, using for the purpose a new method of producing free vibrations, namely by means of solid carbon dioxide (Waller, 1933, 1934, 1937), had lately been undertaken (Waller, 1939), it was decided to obtain observations of the triangular plate also with a view to recording and classifying the modes of vibration in a systematic manner. As the experimental arrangements have been described in earlier papers, it will suffice to mention here that the vibration frequencies were measured by means of a calibrated valve oscillator, and that the plates were sometimes set into vibration with a bow instead of with solid carbon dioxide in cases where the desired nodal system could be obtained efficiently by excitation at the edge of the plate.

§2. THE NODAL SYSTEMS

Preliminary considerations. Although any mode of vibration possible to the right-angled isosceles triangular plate corresponds to some natural mode of the

square plate, the converse statement is not always true. In order to recognize and classify the triangular figures, it is desirable first to know which of the square nodal systems may be expected to have their counterpart on the triangular plate.

The nodal systems of the square plate are given approximately by the Rayleigh-Ritz equation (Rayleigh, 1894 and 1911; Ritz, 1909),

$$\omega = Au_m(x)u_n(y) \pm Bu_n(x)u_m(y) = 0, \qquad \ldots\ldots(1)$$

in which ω denotes the displacement at the point x, y, and $u(x)u(y)$ are the normal functions of a free bar which is equal in length to the side of the plate. Except when the sum $m+n$ is odd, the amplitude constants A and B must be equal. The abbreviated notation $m|n+$ and $m|n-$, which is a modification of Chladni's later notation (Chladni, 1817), may be conveniently used for specifying the nodal figures.

We proceed to show that the only square figures which have their counterpart on the triangular plate are given by

$$\omega = u_m(x)u_n(y) + u_n(x)u_m(y) = 0, \qquad \ldots\ldots(2)$$

where m and n may have any integral values except unity.

In the first place it is seen from conditions of symmetry that there can be no triangular nodal system corresponding to the fundamental $1|1$ system shown in figure 2 of plate 2. The second $2|0-$ tone, with two nodal diameters, will also evidently be missing for the triangle. The third square nodal system, $2|0+$, half of which is given in figure 4 of plate 2, is the first square system which has a counterpart on the triangular plate.*

In order to arrive at general conclusions regarding higher overtones, we may now examine the classified photographs of the square nodal systems previously published (Waller, 1939). These are arranged on a single diagram which exhibits the essential symmetry of the various classes of nodal figures in a systematic manner. In case this diagram is not immediately available, figure 1 of the present paper may be studied instead. In it the various classes of symmetry are represented by descriptive abbreviation-symbols, the meanings of which are explained immediately below the diagram. It will be seen that the systems for which m and n are equal occupy the squares which extend diagonally from the top left corner to the bottom right corner of the diagram. The $m|n+$ systems are situated in the triangular space to the left of, and the $m|n-$ systems are situated in the triangular space to the right of, this diagonal. Both diameters are nodal in the *minus* portion of the diagram when the values of m and n are either both odd or both even; such figures can have no counterpart on the triangle. Remembering that the systems with one nodal diameter, in the *minus* and *plus* parts of the diagram, are only formally distinct from one another, it may be concluded that the triangular systems may be arranged along the diagonal and in the triangular space to the left of this. Conditions of symmetry on the triangle are sufficient to show that additional

* These conclusions may be compared with the simple case of a free bar for which the first tone of the half bar (with two nodal lines) corresponds to the third tone of the whole bar (with four nodal lines).

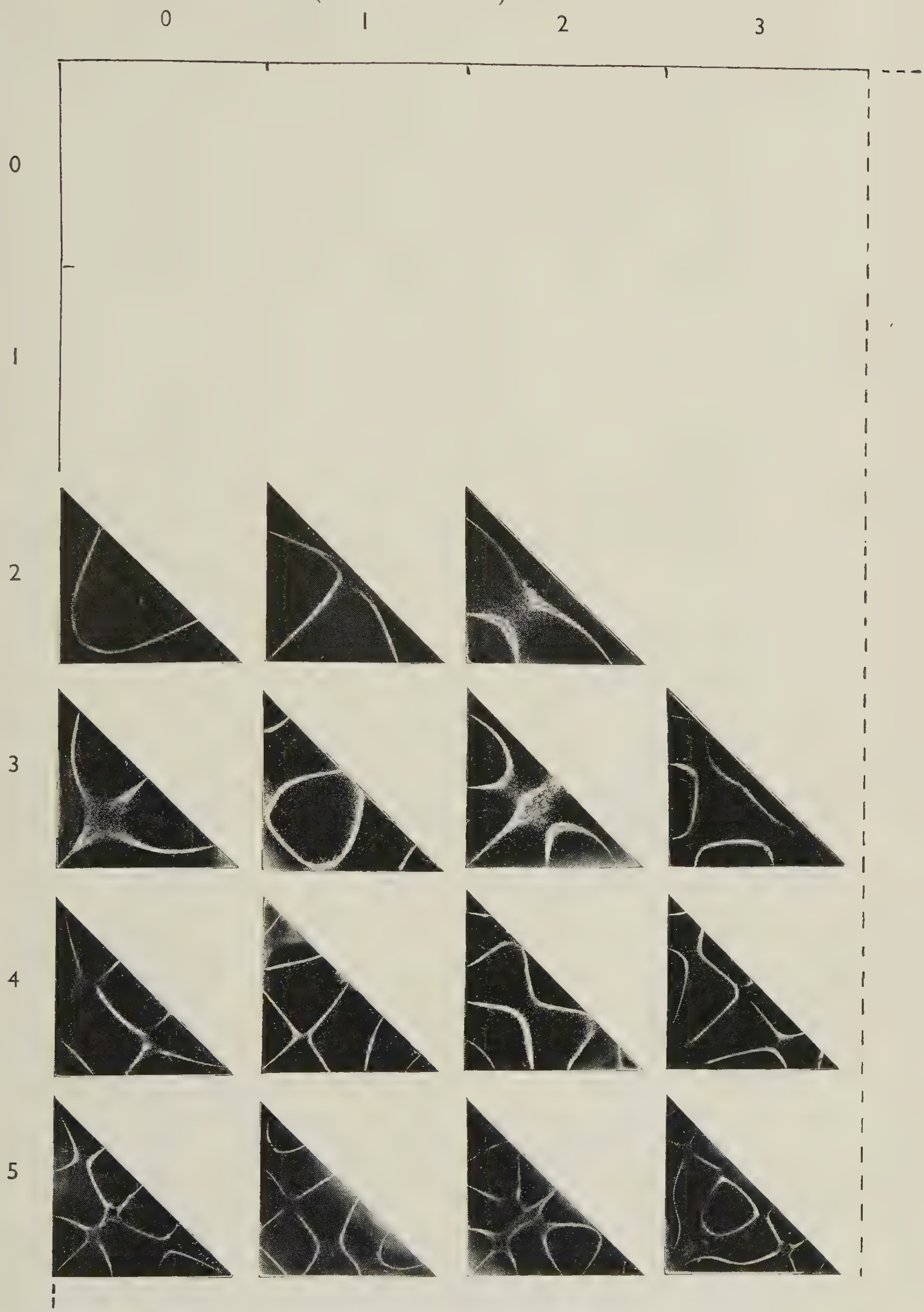
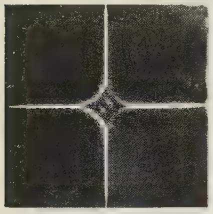
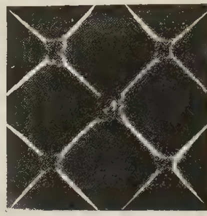


Plate 1. Nodal systems of right-angled isosceles triangular plate.

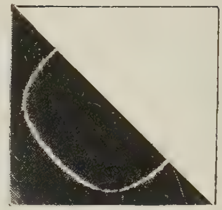
To face page 36



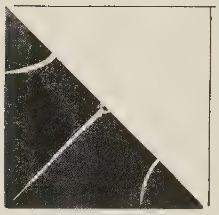
2 1|1



3 4|0-

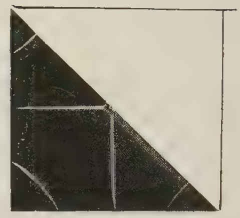


4 2|0+

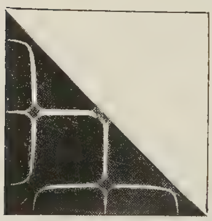


5 2|1

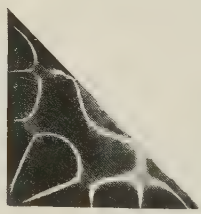
6 2|2



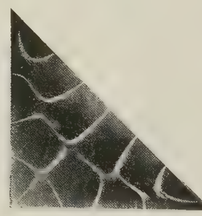
7 3|1+



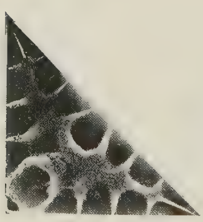
8 3|3



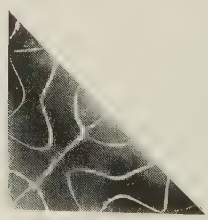
9 4|4



10 6|1



11 6|2



12 7|2

13 6|4

Plate 2. Figures 4 to 8 are *half square* nodal systems to be compared with the corresponding triangular systems in plate 1. Figures 9 to 13, some classified higher overtones.

figures corresponding to unequal values of A and B in equation (1) will not be possible. Thus the only possible triangular figures corresponding to the square figures are given by equation (2).

Experimental results. The photographs of fifteen triangular nodal systems, arranged according to the above plan, are shown in plate 1. In order to obtain some idea of the differences between the actual triangular systems and the bisected-

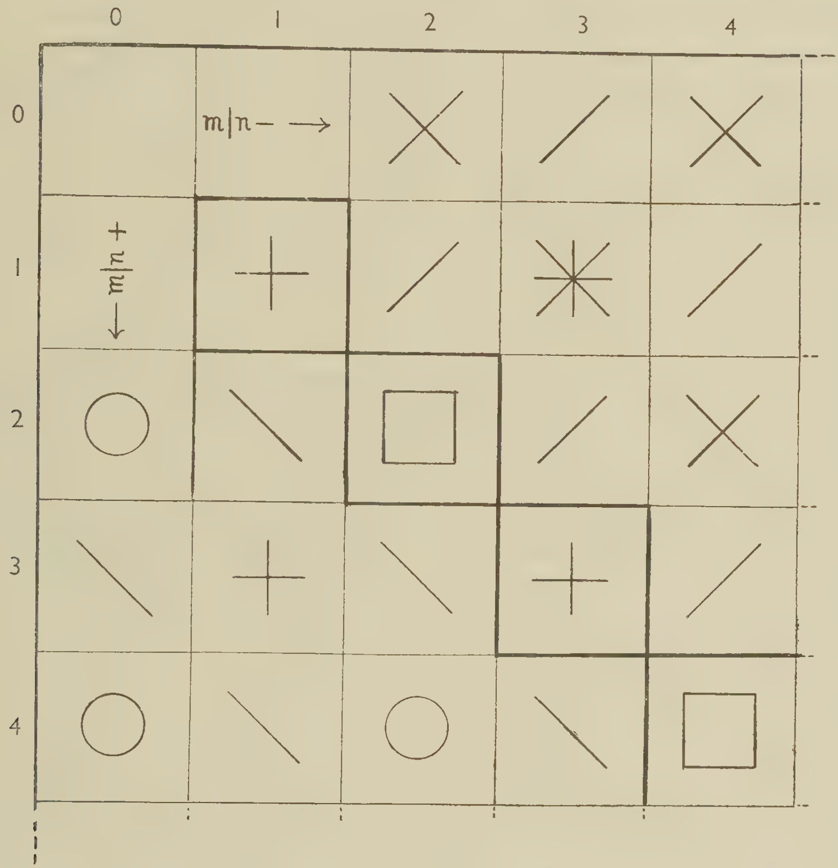


Figure 1. Symbolic classification of nodal systems of free square plate. ○, □ antinodal centre; ╱ one nodal diameter; + medians nodal; × diameters nodal; ✳ medians and diameters nodal.

square figures, some classified examples of the latter, given in figures 4 to 8 of plate 2, may be compared with the relevant triangular systems of plate 1.

It is seen that in some cases, for example the $2|0+$ mode, the shape of the nodal line only is modified, and the figure is immediately recognizable. In other cases, however, for example the $3|1+$ mode, the lines sometimes meet different edges from those of the half-square figures. It is noteworthy that whereas the mid-point of the hypotenuse is always antinodal, except when one of the values m, n is odd and the other even, the centre of the square is never antinodal except in the $m|n+$

class with m and n both even. The fact that all the nodal lines are curved, excepting only the straight bisecting line which occurs when the sum of $m+n$ is odd, may also be noted.

Recognition of the nodal systems. In spite of the above differences, the triangular nodal systems may be recognized in terms of the m, n values of the square plate by using the following rules :—

1. $m=n$. No nodal lines meet the hypotenuse edge ; m (or n) lines cut the shorter edge.
2. *m odd ; n even, or vice versa.* The triangle is bisected symmetrically by a nodal line.
3. *m, n, both even.* $\frac{1}{2}(m+n)$ lines are encountered in traversing the median line to the centre of the hypotenuse.
4. *m, n, both odd.* All figures not included in the above.
5. The sum $m+n$ (except when $m=n$) is usually equal to the number of lines which cut the hypotenuse.
6. The value of m is usually equal to the number of lines which cut a shorter side.
7. In certain cases, rules 5 and 6 must be extended to include curved nodal lines which do not actually cut the edge, but which, if they did so, would cut it twice. (See, for example, the $3|2$ and $3|0$ systems of plate 1.)

Finally, when the natural frequencies are known, (§ 3), they are also of assistance in classifying the figures.

Higher overtones. Attention is drawn to the examples of nodal systems of some higher overtones shown in figures 9 to 13 of plate 2 (13 has been retouched). They were classified by means of the rules which have just been given.

§ 3. THE NATURAL FREQUENCIES

Preliminary remarks. The frequencies of the vibrating modes of a square or triangular plate are proportional to $\frac{1}{a^2}\sqrt{\frac{D}{m}}$, in which a is the length of side, m is the mass per unit area and D is the flexural rigidity ($=Eh^3/12(1-\sigma^2)$), where E is Young's modulus, h the thickness, and σ is Poisson's ratio (Timoshenko, 1937).

Although the relative frequencies of corresponding modes of the square and triangular plate may be expected to be roughly comparable, the actual frequencies of the triangular plate should be lower, since the constraint to which a vibrating surface of given area is subject is evidently reduced by making the diagonal of the square a free edge of the triangle.

Experimental results. The observed natural frequencies and the relative frequencies (in italics) of one of the brass plates employed are shown in the table, which corresponds in its arrangements with the nodal systems of plate 1. The length of the shorter side of this plate was 22·48 cm. and the thickness 2·58 mm.

The fundamental frequency of 162 c./sec. is, as expected, appreciably lower than the corresponding frequency for the square plate which, according to calculation, is 227.

Table. Actual (c./sec.) and relative natural frequencies (in italics) of a right-angled isosceles triangular brass plate arranged to correspond with the nodal systems of plate 1

	0	1	2	3
2	162 *1*	227 *1·4*	380 *2·36*	
3	414 *2·56*	590 *3·65*	710 *4·39*	1090 *6·8*
4	862 *5·32*	1078 *6·62*	1350 *8·36*	1690 *10·4*
5	1380 *8·54*	1670 *10·3*	2000 *12·4*	2490 *15·4*

REFERENCES

Chladni, 1802. *Die Akustik*, § 118.
Chladni, 1817. *Neue Beiträge zur Akustik.*
Rayleigh, 1894. *Theory of Sound*, **1**, chs. viii, ix and x.
Rayleigh, 1911. *Phil. Mag.* **22**, 225.
Ritz, W., 1909. *Ann. Phys., Lpz.*, **28**, 737.
Timoshenko, S., 1937. *Vibration problems in Engineering*, § 70 (second edition).
Waller, M. D., 1933. *Proc. Phys. Soc.* **45**, 101.
Waller, M. D., 1934. *Ibid.* **46**, 116.
Waller, M. D., 1937. *Ibid.* **49**, 522.
Waller, M. D., 1939. *Ibid.* **51**, 831.

A NOTE ON HIGH-TEMPERATURE POSITIVE-COLUMN DISCHARGE TUBES

By R. F. BARROW,
Departments of Inorganic Chemistry and Physics, Imperial College *
* Now at University College, Oxford

Received 30 *July* 1940

ABSTRACT. Two heavy-current positive-column discharge tubes for investigation of the emission spectra of refractory materials are described, together with details of their construction and mode of operation. The temperature necessary for the development of a convenient vapour pressure of the material under examination is attained by degradation of part of the energy of the positive column of the discharge, which is constricted in (i) in the narrow central portion of an all-silica tube, and in (ii) by a small axial hole through a sintered aluminium oxide cylinder, supported centrally in a silica envelope tube.

§ 1. INTRODUCTION

The attention of research workers in the spectroscopy of diatomic molecules was initially directed towards the investigation of those whose spectra were easily obtained, either in emission or in absorption. The majority of the diatomic emitters studied were either stable molecules, or radicals produced from molecules, which possess a convenient vapour pressure at temperatures of, at most, a few hundred degrees Centigrade. Exceptions were those radicals excited by arcs, in air, *in vacuo*, or in presence of a foreign gas, under conditions where only the most stable compounds can survive the vigorous thermal and chemical attack. The extension of the positive-column type of discharge tube to the examination of the emission spectra of refractory materials at high temperatures is a comparatively recent development. The present note gives details of two such discharge tubes which have been used to excite the spectra of substances requiring temperatures of 1000° c. or more for their volatilization at convenient pressure into the discharge. The tubes are greatly to be preferred to the arc techniques, both on account of standardization and maintenance of working conditions, and also in virtue of their economy in usage of materials. The former allows the realization of chemical synthesis under carefully specified conditions in the discharge itself, while the latter considerably reduces the cost of spectroscopic research with rare materials. The successful production of the spectra of GeO, GeS, GeSe and GeTe recorded elsewhere illustrates both these points (Barrow and Jevons, 1940). The tube to be detailed first was demonstrated

at a meeting of the Society on 24 May 1940, and has already been briefly described in connection with the production of the band spectrum of silicon monosulphide (Barrow and Jevons. 1938): it seems, however, of interest to summarize here additional experience as to its behaviour and running conditions which has accrued in later experimental work, together with the details of its construction.

§ 2. A SILICA DISCHARGE TUBE OF SIMPLE CONSTRUCTION

The tube is illustrated in figure 1. The large horizontal tubes containing the electrodes are of vitreosil about 30 cm. long and about 2·5 cm. internal diameter. One of them has a waxed-on quartz window W, and a branched side-tube T, mostly of vitreosil, which serves the double purpose of admitting a gas or vapour and of supporting the pyrex sleeve S_1 which surrounds the nickel wire leading to the electrode E_1 : the other is closed by a rubber stopper through which pass the pyrex sleeve S_2 of the other nickel lead and the exit tube leading to the pump. The electrodes are sheet nickel cylinders about 15 cm. long. The narrow central

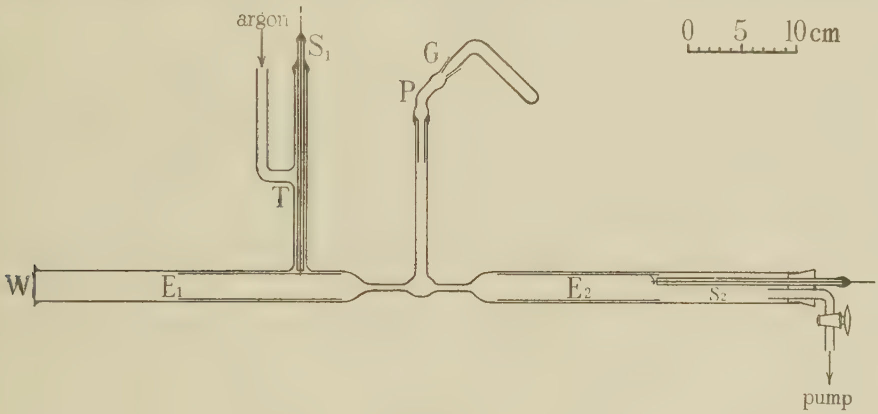


Figure 1. Silica discharge tube.

tube, in which the positive column of the discharge is concentrated, is of clear silica about 10 cm. long and about 0·6 cm. internal diameter. A bent pyrex tube P with a ground conical joint G is connected to the upper end of this with sealing-wax. It supports a bent and closed tube containing the materials to be admitted to the positive column as and when required. Economy is effected by making the tube largely of vitreosil: the practical difficulty of blowing satisfactory vitreosil-to-vitreosil seals is overcome by the interposition of short lengths of clear quartz, as sound vitreosil-to-clear-quartz joints can be made without difficulty. Rather drastic cleaning of the tube from metallic oxides by alkali, followed by treatment with a strong hydrofluoric acid solution, is advisable from time to time, but with this attention the tubes are serviceable for long periods, and attack may be confined to the central portion, which is easily replaced.

Current for the tube has been taken from two 5-kva. transformers connected in parallel, and up to 5 amp. at 2000 v. can be put through the tube for short

periods : the temperature attainable in the central portion by degradation of part of the energy of the positive column of the discharge is only limited by its area of cross-section and by the melting point of the silica. When working with materials which readily attack silica at high temperatures, it is advisable to introduce a sleeve tube in this central portion, which then protects the envelope from disintegration. The tube is operated at the highest pressures at which the discharge will pass, i.e. about 10 mm. : at lower pressures a disproportionately large amount of energy is dissipated at the electrodes. It is unnecessary to use a rare gas as residual element to conduct the discharge before the tube warms up, about 10 mm. of air being employed in presence of aluminium powder, which then removes the O_2 and N_2 at higher temperatures. This aluminium serves the additional function of inhibiting the introduction of silicon compounds into the discharge, by the formation of an inert lining of, presumably, an aluminium silicate. Spectra of these silicon compounds, particularly SiO and SiS, are otherwise capable of constituting unwelcome impurities in much the same way as the familiar CO and CS spectra in low-temperature discharges.

§ 3. ALUMINIUM OXIDE - SILICA - PYREX DISCHARGE TUBE

The tube just described has proved to be of use in a number of investigations. Its limitations are those imposed by the silica of its construction, and accordingly a tube has been made in which the vital component is of sintered aluminium oxide. At the same time the necessity for any silica blowing has been obviated. The tube is illustrated in figure 2, where the letters have the same significance as in figure 1. In principle it is a modification of the discharge tube described by Pearse and Gaydon (1938), in which the positive column is constricted in a silica

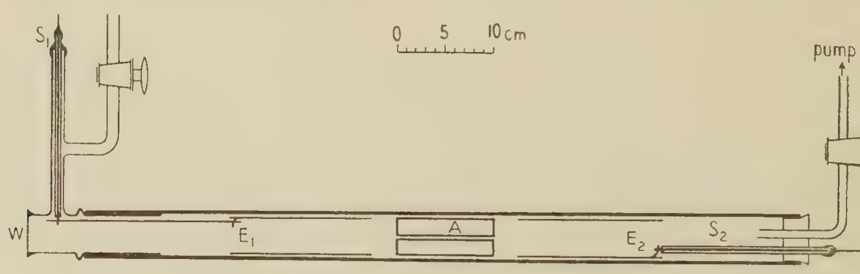


Figure 2. Alumina-silica-pyrex discharge-tube.

tube, centrally and axially supported in a water-cooled pyrex envelope. In the present case, the discharge passes through an axial hole of about 4 mm. diameter in a cylindrical block of sintered aluminium oxide, A, about 10 cm. long, which replaces Pearse and Gaydon's silica positive-column tube. A glazed vitreosil envelope is used in place of pyrex, and the pyrex tube carrying the window W and the electrode lead S_1 is sealed into it with wax. The aluminium-oxide block is packed into the envelope with asbestos wool, allowing for the thermal expansion

of the block. Sintered aluminium oxide is far more inert chemically than silica at high temperatures, and has a considerably higher melting point (about 2100° c.). Accordingly this tube possesses advantages over the all-silica type of the previous section in its low chemical reactivity and higher temperature limit, and also in its simplicity of construction. The ease of introduction of material into the positive column of the discharge, an important characteristic of the first tube, has necessarily been sacrificed.

§4. ACKNOWLEDGEMENTS

The author desires to express his gratitude to Dr. W. Jevons, Dr. R. W. B. Pearse and Dr. A. G. Gaydon for helpful discussion. Thanks are also due to the Council of the Royal Society for permission to reproduce figure 1 from the *Proceedings of the Royal Society*.

REFERENCES

Barrow, R. F. and Jevons, W., 1938. *Proc. Roy. Soc.* A, **169**, 45.
Barrow, R. F. and Jevons, W., 1940. *Proc. Phys. Soc.* **52**, 534.
Pearse, R. W. B. and Gaydon, A. G., 1938. *Proc. Phys. Soc.* **50**, 201.

NOTE ON A SIMPLE TEST OF THE INVERSE-SQUARE LAW FOR MAGNETISM

By ALLAN FERGUSON and ERIC J. IRONS,
Queen Mary College *
* Now at King's College, Cambridge

Received 22 *August* 1940

ABSTRACT. A test of the inverse-square law for magnetism may be made by varying the distance d between the deflecting magnet and the magnetometer needle, keeping the former always parallel to its initial position (the B position of Gauss). With an inverse nth law, d^2 is a linear function of $\cot^p \theta$, where $p=2/(n+1)$. In an illustrative experiment, n was found to be 2·00.

The method also permits the evaluation of M/H, where M is the moment of the magnet and H the earth's horizontal field.

When M/H has been determined, it is not essential to carry out a dynamical experiment to obtain MH, and hence H. As Töpler originally pointed out, weighings on an ordinary balance suitably disposed suffice to determine MH.

The usual laboratory method of testing the inverse-square law depends on experiments made in the Gauss A and B positions (or in the sine-modifications suggested by Lamont (1867)), when we have, in the simplest form, for the Gauss positions,

$$\tan \theta = n \tan \phi. \qquad \ldots\ldots(1)$$

This formula, of course, assumes a magnet of which the magnetic length l is very small in comparison with the distance d between its centre and that of the (small) magnetometer needle, so that l^2/d^2 is negligible in comparison with unity.

If this condition is not fulfilled then, assuming the existence of pole-centres, it is easy to show that

$$\tan \theta = n\left(1 + \frac{(n+1)(n+5)}{6}\frac{l^2}{d^2} + \ldots\right) \tan \phi, \qquad \ldots\ldots(2)$$

where terms of order higher than l^2/d^2 are neglected (see, for example, Glazebrook and Shaw, 1902).

But it is not usually appreciated that a test of the inverse-square law may be made from a single set of experiments in the Gauss B position. For we have, assuming the inverse nth law and a schematic magnet, $M/(d^2+l^2)^{(n+1)/2}$ as the expression for the intensity at points on the equatorial axis of the magnet. This leads at once to

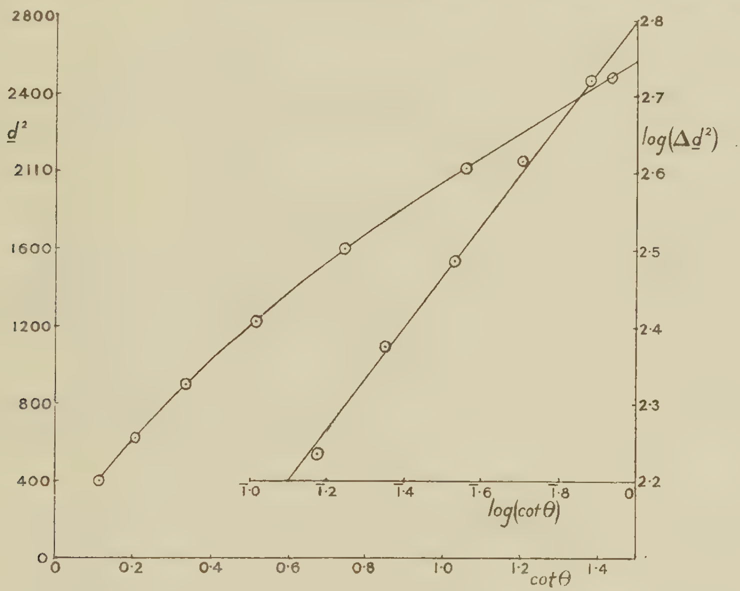
$$d^2 = -l^2 + (M/H)^p \cot^p \theta, \qquad \ldots\ldots(3)$$

giving the deflection θ of a small magnetometer needle at a distance d from the centre of the deflecting magnet. In (3) p is written for $2/(n+1)$, and the equation has the advantage of being exact in the sense in which (1) and (2) are not exact; that is to say, no restrictions are made concerning the smallness of the ratio l^2/d^2.

If values of d^2 are plotted as ordinates, $\cot\theta$ as abscissae, equation (3) takes the form

$$y=a+bx^p, \qquad \ldots\ldots(4)$$

and the values of the constants p, a and b are easily obtained by a graphical method suggested by Running (1917). The curve between y and x is drawn, and is fitted as closely as possible to the experimental points by means of a suitable spline.



Points on the curve are chosen whose abscissae are in a suitable geometrical progression of known common ratio r. If, corresponding to x, rx, . . ., we have ordinates y, $y+\Delta y$, . . . , it follows at once from (4) that

$$\log\Delta y=p\log x+\log b(r^p-1). \qquad \ldots\ldots(5)$$

A plot of $\log\Delta y$ and $\log x$ is therefore linear; the slope of the line gives p, the intercept gives b, and from every pair of values of x and y, (4) gives a value of a, of which the mean may be taken.

The object of this note is to show what may be done with quite simple apparatus. The magnetometer employed consisted of a short needle provided with pointers moving over a circular scale which could be read to a quarter of a degree. The deflector was a cobalt-steel magnet of magnetic length 18·1 cm. as determined by a search compass. The usual readings of θ were taken for each value of d, and means of θ were calculated to the nearest eighth of a degree. The values of θ varied from about 35° ($d=50$ cm.) to 85° ($d=20$ cm.).

The figure shows on a reduced scale the curves between d^2 and cot θ, and between log Δd^2 and log cot θ (the common ratio r for the geometrical progression of the abscissae was 1·5). The second graph is satisfactorily rectilinear, and the slope p is (0·600/0·90), giving a value of n equal to 2·00.

The main object of the experiment is the determination of n, but it may be worth noting that the intercept gave a value of M/H of $9\cdot 14\times 10^4$ cm.^{3} The values of l^2, calculated in the manner described, were 80, 81, 68, 80, 82 and 85 cm.^{2}, giving a mean value for $2l$ of 17·9 cm. (compared with 18·1 cm. as determined with a search compass). Mr. Awbery has suggested that a method similar to that used by one of us (Ferguson, 1916) in calculating surface-tension temperature-coefficients might with advantage be used here. Equation (4) gives

$$x\,.\,\delta y/\delta x = pbx^p = p(y-a),$$

so that $x\,.\,\delta y/\delta x$ is linear in y with slope p. The method enables one to deal directly with the observed figures, rather than with points on a smoothed curve.

As a matter of pedagogic interest, it may be noted that, if the results of this (or any similar deflection experiment) be combined with those of a nearly-forgotten experiment due to Töpler (1884), a determination of M and of H may be made by purely statical methods. In Töpler's experiment the magnet is fixed rigidly in a vertical position to the arm of a fairly sensitive balance. The beam is placed in the magnetic meridian, and the balance is equilibrated. The beam is then rotated through 180° and again equilibrated. If m is the difference in the masses required to equilibrate the balance and L the length of the balance arm, clearly

$$2MH = mgL.$$

Thus, with the magnet used in the experiment just described, if $H = 0\cdot 2$ oersted, and $L = 20$ cm., the value of m is about 0·4 gm.

REFERENCES

Ferguson, 1916. *Phil. Mag.* **31**, 37.
Glazebrook and Shaw, 1902. *Practical Physics*, p. 471.
Lamont, 1867. *Handbuch d. Magnetismus*, p. 279.
Running, 1917. *Empirical Formulas*, p. 48.
Töpler, 1884. *Ann. Phys., Lpz.*, **21**, p. 158.

ON ALTERNATING-CURRENT BRIDGES WITH INCOMPLETE BALANCE

By ALBERT CAMPBELL, M.A.,
Cambridge

Received 5 *September* 1940

ABSTRACT. The paper classifies bridges in which the detector deflection is not brought to zero, but only to a minimum, and shows by several examples how this procedure can give useful results in various special cases.

---

§ 1. INTRODUCTION

In A.C. bridges containing inductance or capacitance, in order to obtain a balance it is usually necessary to alter two components, e. g. resistance and inductance. Several cases may be considered.

Case 1. Normal

When the detector shows zero deflection, two equations can be formed, from which two desired unknown quantities can generally be found.

Case 2

When only one of the components is varied, complete balance cannot usually be obtained. But we can always vary one of the components so as to make the detector current a minimum. From the equations for this minimum condition we can sometimes find one unknown component, but not two.

Case 3

Sometimes, however, the equations involve impossible conditions, and indicate that no complete balance can be obtained by varying the two components chosen. The minimum method is often helpful here.

§ 2. PARTICULAR CASES

It is not easy to suggest any general formula to include these three cases, and accordingly it seems best to investigate each particular bridge separately, as I proceed to do in the following examples. It is not necessary to discuss Case 1 further, as nearly all well-known A.C. bridges (with complete balance) are included in it.

As an example of Case 2 let us consider the ordinary self-inductance bridge

shown in figure 1, in which the ratio arms are equal ($R=R$), P and L are known and Q and l are to be determined.

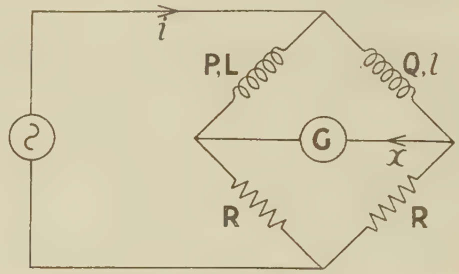


Figure 1

Let i and x be the instantaneous values of the currents from the source and in the detector (G) respectively, I and X being the corresponding effective (R.M.S.) values. Let $g+hj\omega$ be the symbolic impedance of the detector, which may be assumed constant. Here, as also in the other examples, the detector may be of R.M.S. type such as an electrodynamometer or a D.C. galvanometer with rectifier. Then

$$\frac{x}{i}=\frac{R[P-Q+(L-l)j\omega]}{2R(P+Q)+\mathrm{F}g-h(L+l)\omega^2+[(2R+g)(L+l)+\mathrm{F}h]j\omega}, \quad \ldots(1)$$

where $F=P+Q-2R$.

In this general case, when I is constant, variation of only one component (say P) to give X minimum leads to a complicated result. But let $P+Q$ be kept constant ; then

$$\frac{X^2}{I^2}=\frac{R^2[(P-Q)^2+(L-l)^2\omega^2]}{D}. \quad \ldots\ldots(2)$$

where D does not vary with changes of P and Q.

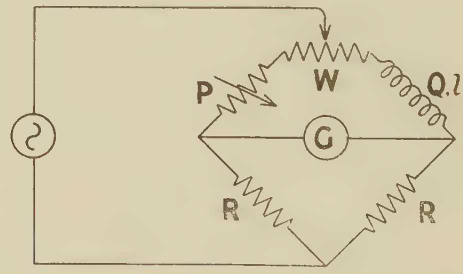


Figure 2.

Thus X is minimum for variation only of P and Q when $Q=P$.

A useful application of this system is shown in figure 2, in which L is made zero. P is altered in steps until a minimum X can be got by adjustment on the slide-wire W. Then $Q=P$, and the effective resistance of the l-coil is obtained without the use of any other inductor. The method works well in practice.

If the l-coil is replaced by a condenser, its effective resistance can similarly be found and the power factor determined; but this system is not easy in practice.

Carey Foster bridge

In the Carey Foster method of measuring capacitance and power factor, a similar investigation shows that the method of minimum deflection does not give clear results, and thus complete balance by double adjustment is always desirable.

Examples of Case 3

Campbell's M, C frequency bridge shown in figure 3 is an example of Case 3. In this figure the detector circuit (Q, L) includes the secondary of the mutual

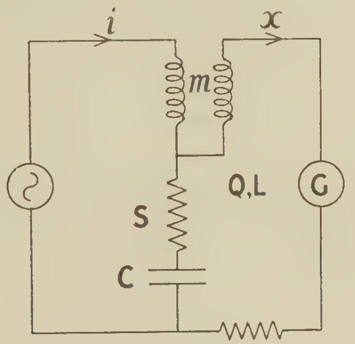


Figure 3.

inductance m, while the series resistance S includes the loss in the condenser C and the impurity of m.

Then

$$\frac{x}{i}=\frac{S+\left(m-\dfrac{1}{C\omega^2}\right)j\omega}{Q+S+\left(L-\dfrac{1}{C\omega^2}\right)j\omega}.$$

Therefore

$$\frac{X^2}{I^2}=\frac{S^2+\left(m-\dfrac{1}{C\omega^2}\right)^2\omega^2}{(Q+S)^2+\left(L-\dfrac{1}{C\omega^2}\right)^2\omega^2}. \qquad \ldots(3)$$

The conditions for complete balance ($X=0$) are $m=1/C\omega^2$ and $S=0$, which latter is usually impossible. But, keeping I constant, variation of m gives X minimum when

$$m=1/C\omega^2 \quad \text{or} \quad \omega^2=1/Cm,$$

and the frequency is found correctly without knowledge of the condenser loss or the impurity of the inductor.

The method was tested for frequencies of 50 c./sec. and various audio-frequencies. The results showed very little variation when S was increased by large additions (up to 1000 ohms).

As another example of Case 3, figure 4 shows a condenser bridge suggested by Dr. S. J. Smith as being simpler than the Carey Foster bridge, which it somewhat resembles.

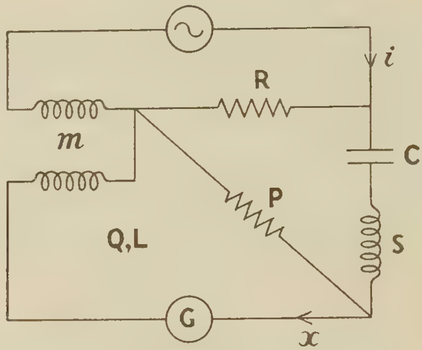


Figure 4.

Let C be the capacitance to be tested, S representing its internal loss, P and R fixed resistances, m a variable mutual inductance, with A.C. source and detector as shown, and let the whole detector circuit be (Q, L).

When m only is varied (with I constant), it can be shown that

$$\left[(P+R)(Q+R)-R^2-L/C+\left\{(P+R+S)L-\frac{Q}{C\omega^2}\right\}j\omega\right]x$$
$$=[PR-m/C-(P+R+S)mj\omega]i. \qquad \ldots\ldots(4)$$

The conditions for complete balance are

$$PR=m/C \quad \text{and} \quad P+R+s=0;$$

complete balance is therefore impossible as $(P+R+s)$ cannot be zero.

It can be shown, as in the former examples, that X is a minimum when

$$m=\frac{CPR}{1+C^2(P+R+s)^2\omega^2}. \qquad \ldots\ldots(5)$$

Very often $C^2(P+R+s)^2\omega^2$ is fairly small compared with unity, but since s is not known the equation (5) is quite uncertain. The inability to determine s is the weak point of the method.

A third example of Case 3 is the Mutual Shunt method of measuring self-inductance which I described not long ago (Campbell, A., 1938). The chief difficulty in this arises from the impurity of the inductometer.

It will be seen from the above examples that methods with incomplete balance can often be used with advantage.

§ 3. ACKNOWLEDGEMENT

My thanks are due to Dr. S. J. Smith for kind permission to publish his method.

REFERENCE

CAMPBELL, A., 1938. *Proc. Phys. Soc.* **50**, 655.

A NOTE ON THE ELECTRIFICATION OF POWDERED INSULATORS

By Sir AMBROSE FLEMING, F.R.S.

Received 7 *September* 1940

SINCE the presentation of my paper to the Physical Society, on 28 April 1939, on "A new method of creating electrification" a contribution on the same subject has been made by Dr. Robert Schnurmann (1940) in which experiments made by Coehn and Lotz are described concerning the electrification of powdered dielectrics. I have verified most of the results mentioned. I find, as stated, that it is not necessary to allow a powder of some insulator to fall on a perforated zinc plate, but some electrification of the powder can be obtained by allowing it to fall on a metal plate connected to an electroscope, provided the silica powder does not remain on the plate but falls off it instantly. Silica powder was used in the above-mentioned work of Coehn, but I have found that powdered sulphur gives good results. The sulphur must be prepared from crushed and sifted roll sulphur. Flowers of sulphur does not flow easily enough out of a containing vessel.

My experiments were made as follows:—A bottom portion of a tin canister, three inches in diameter and three inches deep, was placed on the plate of an electroscope. On pouring into this tin receptacle powdered silica in a continuous stream from a glass or metal vessel held about a foot above the receptacle, the gold leaves of the electroscope diverge and show a negative charge given to it. The results are, however, very variable. In the case of some glass bottles or vessels the electrification of the silica powder poured from them is very strong, and for other glass vessels little or no electrification is shown. Sulphur powder, even in small quantities, poured into the receptacle gives strong negative electrification far more than silica. The most uniform results I find are obtained when the powder of silica or sulphur is poured from a glass or metal container into a small tin funnel held above the receptacle on the electroscope, so that a steady slender stream of particles falls into the receptacle.

If the receptacle is lined with paraffined paper made by soaking white paper in melted paraffin wax, the electrification obtained is nearly as great as when the bare metal receptacle is used. This shows that the charge is not entirely due to the particles of insulator impinging on metal, but that the charge on the insulating powder must partly be obtained when it leaves the spout of the tin or glass funnel. But the electrification does depend in some degree on the velocity with which

the particles strike the receptacle. Only when good insulators such as silica or sulphur are employed as powders is any electric charge obtained. I have tried carborundum, bauxite, emery and rochelle salt in powder without results, but all these substances in powder form have some degree of conductivity for electricity. The most uniform results are obtained when powdered silica or sulphur is poured from a height of several inches on a perforated zinc plate held over, but not touching, the receptacle on the electroscope. We then find that a strong negative charge is given to the electroscope by the powder which has passed through the holes in the perforated zinc plate.

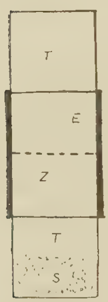


Figure 1.
TT, tin canisters; *E*, ebonite tube;
Z, perforated zinc plate; *S*, silica powder.

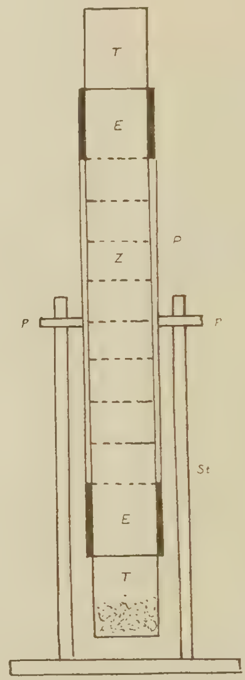


Figure 2.
TT, tin canisters; *EE*, ebonite tubes;
Z, perforated zinc plates ; *pp*, pivots;
PP, card tube; *St*, stand.

Based on this fact I have made a little apparatus by which an unlimited amount of negative electricity can be obtained by the use of a single small quantity of silica powder by causing the powder to fall again and again through a perforated zinc plate. The apparatus is made as follows :—An ebonite tube about four inches in diameter and six inches long has a partition of perforated zinc placed across it at its centre (see figure 1). The ends of this tube are closed by tightly fitting tin canisters, and in one of these a charge of about $\frac{1}{4}$ or $\frac{1}{2}$ a pound of well-dried silica is placed. If the apparatus is held in a vertical position the silica all falls into the bottom canister. If the tube is then turned over like an hour-glass or egg-boiler, the silica comes into the top and falls down again through the perforated zinc

partition into the lower cylinder. It thus gives to that cylinder a negative charge of electricity. This charge can be put into an electric condenser formed of two metal plates separated by a thin sheet of ebonite. The apparatus can then be reversed in position many times, and at each reversal the silica conveys a negative charge to the lower cylinder and to the condenser. If then the condenser plates are separated by insulating handles, their electric capacity is reduced and potential raised, and if the two condenser plates are brought close together a small electric spark can be seen.

I have also found that by allowing the silica to fall through several perforated zinc plates in succession the charge is increased. Hence another apparatus has been made, as follows:—A card tube of square section, about 42 inches long and 4 inches inside, has about ten partitions of perforated zinc placed across it at intervals of four inches (see figure 2). The ends of the card tube are closed by short ebonite tubes, and these again by tin canisters to form receptacles for the silica. The card tube is enclosed in a wood tube, and at the centre, pivots are placed by which it is supported in a suitable stand to enable it to be turned upside down repeatedly. At each such reversal the charge of silica powder falls through the ten perforated zinc partitions and gives a charge of negative electricity to the lower cylinder. By repeated reversals of position of the tube the electric charges produced can be put into an electric condenser and so accumulated as above described.

The point to be particularly noticed is that success in these experiments can only be obtained if the silica powder is very well dried by heating it for some time to above 100° C. just before using it.

One conclusion which may be drawn from the foregoing experiments is that when particles of a good insulator, that is, one with few or no free electrons in it, strike with some velocity a metal surface or one in which there are many free electrons, electrons tend to pass from the medium in which the electron density is large to the one in which it is small. Hence the particles of silica or sulphur carry with them when they bounce off or pass through the metal sheet a negative charge. If these particles fall into the interior of an insulated canister connected to an electroscope they give a negative charge to the electroscope. I find also that if these negatively charged insulator particles fall into a space filled with water-cloud such as is created by slightly condensed steam (e.g. that given from the spout of a kettle), the particles act as condensation nuclei and form larger water particles or rain, thus dissipating the cloud sooner than it would disappear if left to itself.

This assumption explains quite clearly all the facts noticed in the above-described experiments.

REFERENCES

Fleming, Sir J. A., 1939. *Proc. Phys. Soc.* **51**, 402.
Schnurmann, R., 1940. *Proc. Phys. Soc.* **52**, 179.

OBITUARY NOTICES

Sir OLIVER JOSEPH LODGE, D.Sc., Sc.D., LL.D., F.R.S.

Born 12 June 1851. Died 22 Aug. 1940

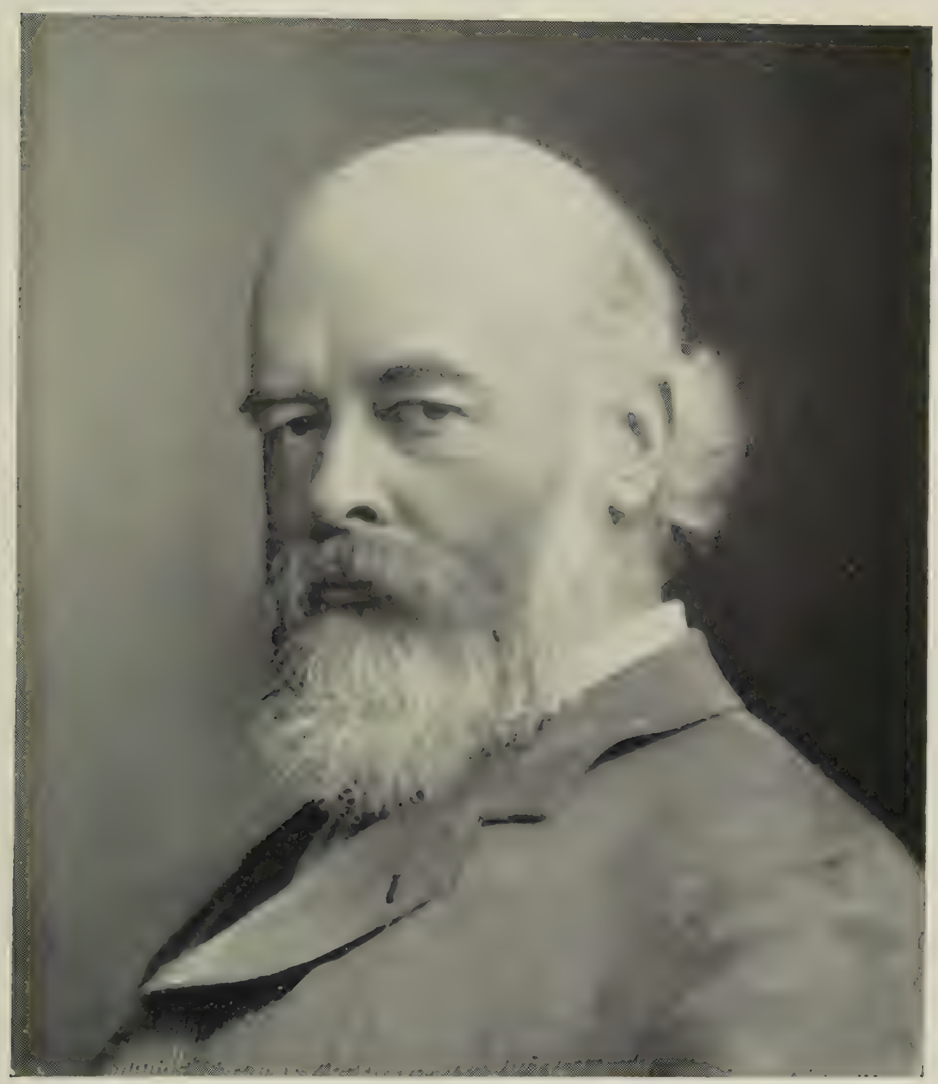
BIOGRAPHICAL SKETCH

The memory of Oliver Lodge bridged the gulf of years that lies between the Indian Mutiny and the War which is now shaking the foundations of our civilization; between a world in which the electric telegraph and railway locomotion were still novelties, and one which is reaping the doubtful benefits of the discovery of aerial locomotion; between a world in which the atomic theory was awaiting rehabilitation at the hands of Cannizzaro, and one where the classical concept of the atom, after suffering many a sea-change, has been engulfed by the rising tide of quantum-mechanical theory. In many of these changes, Oliver Lodge's work has played a prominent part.

Lodge was born at Penkhull, near Stoke-upon-Trent, where his father held a prosperous and growing agency, which he had built up himself, for the supply of materials used in the pottery industry. Unremitting work was the note of the Lodge household; and Lodge's mother, a remarkable woman, found time, in a country home, to run the house, to manage stackyards and poultry-yards, paddocks, and hayfields, to keep the books of the business, and, as a minor matter, to take up photography (by the wet process, be it borne in mind) as a hobby. Young Lodge spent the years from eight to fourteen as a boarder in schools at Newport (Salop) and at Combs (Suffolk), where he was put through the customary classical drill, and suffered many of the customary brutalities which were features of the schools of the period.

At fourteen his schooling was cut short; his father expected him to inherit the business which he had developed, and brought him home to take part in it. From this age, until he had reached his twenty-second year, Lodge was immersed in office work.

But not wholly; a kindly and farseeing aunt, who had already introduced him to some knowledge of astronomy, whisked him away on periodical visits to London, where he attended chemistry classes at the College of Chemistry in Great Marlborough Street, geology lectures at King's College, and, above all, Tyndall's lectures on heat at the Museum of Geology in Jermyn Street. This last-named course, as Lodge said, was an eye-opener, and probably was a deciding factor for his future. As Maxwell did, he began to experiment at home with primitive apparatus, and with the now almost forgotten but still useful *Penny Cyclopaedia* as a work of reference. He attended Science and Art classes at



SIR OLIVER JOSEPH LODGE.

To face page 54

Burslem, and he won an exhibition, under the Science and Art Department, which brought him, with his father's unwilling assent, to the Royal College of Science at South Kensington. Huxley, Frankland and Guthrie were the presiding deities; but their lectures did not suffice to satiate Lodge's curiosity, and he added to their courses evening lectures in mathematics, mechanics and physics at King's College. Then followed a period of study at University College, where he read mathematics under Henrici and Clifford, and where Carey Foster gave him a post as démonstrator. The matriculation examination of London University was passed in 1871, the first and second examinations for the B.Sc. degree followed rapidly, and in 1877 Lodge took his D.Sc. examination. He was wont to say that of all examinations, he found matriculation the hardest.

At about this time he was appointed to teach physics at Bedford College under Barchesterian conditions. One spiral staircase in the vestibule took the (male) lecturer down to an austere waiting, or staff, room in the basement; another spiral staircase took him up to the lecture-room door. The bell rang; the students entered, guarded by an elderly chaperon, complete with knitting. The lecture over, a reverse process, by way of the spiral staircases, decanted the lecturer into the street.

During the years 1875–80, Lodge published papers on the flow of electricity in plane sheets, on models illustrating the flow of electricity through various media, on thermo-electric phenomena, on thermal conductivity, on the foundations of mechanics and on Hughes's induction balance.

In 1881 he was appointed to the chair of physics at the newly-instituted University College in Liverpool, and was fairly embarked on his life's work. He built up the department *ab initio*, and there carried out those researches which resulted, in 1898, in the award of the Royal Society's Rumford medal. The official terms of the award tell the story of Lodge's chief contributions to the advancement of science. After remarking on the simultaneous work of Hertz and of Lodge the report proceeds:

"The researches of the English and German physicists were entirely independent, and, though the merit of the actual discovery of electro-magnetic radiation belongs certainly to Professor Hertz, there seems little reason to doubt that Professor Lodge's experiments would have led him eventually to the same result... When the discovery of electro-magnetic radiation was announced, Professor Lodge...by his experimental investigations...added considerably to the knowledge of the subject... Professor Lodge's introduction of the 'coherer' ...as a substitute for the Hertz 'resonator' has increased in a marked degree the facility for reproducing and extending the experiments of Professor Hertz..."

"With the object of obtaining some information as to the properties of the ether, and of ascertaining whether any mechanical connexion can be detected between matter and ether, Professor Lodge carried out an elaborate series of experiments... His method of observation is to divide a beam of light into two of equal intensity, and to cause the latter to traverse in opposite directions an

annular space in a steel disk. The two beams are superposed so as to produce interference bands. If any appreciable motion can be communicated to the ether in the annulus by causing the disk to revolve rapidly round the common axis of the disk and annulus, it is practically certain that some change must be produced in the velocity of light in the two beams, and this change must show itself by an observable displacement of the interference bands".

As all the world knows, the displacement was *not* observed, and the interpretation then given to this negative result was that matter had no hold that could be detected on the ether in its vicinity.

Lodge made many contributions to the physical science of his day, but his work on electro-magnetic radiation, and his heroic experiments on the relative motion of ether and matter are outstanding.

With his appointment as Principal of the University of Birmingham in 1900, Lodge's major contributions to physical science ceased. As is well known, he devoted much of his overflowing energy to psychical research, and held pronounced views on the possibility of human survival.

In the domain of physics, Lodge was himself his severest critic. Although he does not put it quite in this way, he had, like Henry Bradshaw, a tendency to be "always doing something else". The late Lord Rayleigh remarked to him, concerning his discovery of the coherer, "Now you can go ahead; there is your life-work". But, as Lodge said, "I didn't, ... though I went on with it more or less at intervals; but I attended to many other things as well, and the result was that Maxwell's ether waves ... were mainly worked out and developed practically by others".

The British Association influenced greatly Lodge's life and thought, and he was a faithful attender of its meetings for some sixty-three years—his first meeting was the Leeds meeting of 1873, his last, the meeting at Blackpool in 1936. He missed very few meetings ,and was probably the last survivor of that body of members who listened in 1874 to Tyndall's Belfast Address, in an atmosphere which grew "more and more sulphurous as the materialistic utterances went on in that strongly Protestant atmosphere of Northern Ireland". At the Cardiff meeting in 1891 he was President of Section A, and in 1913 he was President of the Association.

So with the Physical Society. As a young physicist in London in 1874, working with Guthrie and with Carey Foster, he was naturally in close touch with the movement which resulted in the formation of the Society. Though he attended its meetings from the beginning, his formal membership dates from 1875, and he was a regular attender at its meetings and contributor to the pages of its *Proceedings*, until he took up his work at Liverpool in 1881. He occupied the presidential chair during the years 1899–1901, and to the last the Physical Society ever claimed, and held, a large share of his affections.

Lodge's connexion with the *Philosophical Magazine* was long and intimate. It began as far back as the middle 'seventies, when he published in the Magazine

his early papers written in collaboration with Carey Foster, and continued to the day of his death. In 1912 he accepted an invitation to join the editorial board, and for twenty-eight years his wide knowledge of science and of men has been of inestimable service to the Magazine.

Lodge's impressive personality, his gifts of expression and his great power of exposition contributed to the commanding position which he held in the world of science. He will long be remembered as a great teacher; to those whose good fortune it was to know him well, he will live in memory as the kindly friend whose wise advice and counsel were ever freely placed at their disposal. Their world, and the world at large, is richer for his presence among them. A. F.

LODGE AND THE PHYSICAL SOCIETY

My acquaintance with Lodge began when we both entered the chemical laboratories of the Science Schools at S. Kensington 68 years ago. These laboratories had been equipped for the training of science teachers, and the Professor of Chemistry was Dr. E. Frankland; of Physics, Dr. F. Guthrie; and of Biology, Dr. T. H. Huxley. I remember Lodge then as a tall youth in a green baize apron beginning to work at qualitative chemical analysis under a teacher called Valentin. We had near-by benches, and when we began to talk we found we had both more interest in Physics than in Chemistry. New avenues of physical research were opening out just then. Crookes was carrying on his work on electric discharge in high vacua, and Clerk Maxwell was just about to publish his great treatise on electricity, in which he had expressed Faraday's ideas in mathematical language. Lodge and I were both deeply interested in Maxwell's conception of electromagnetic waves and had many discussions thereon.

Dr. Guthrie had seen that the time was opportune for the formation of a Physical Society, and young physicists welcomed it as giving a chance to them to clarify their ideas. I had the privilege of reading the first paper on a subject Lodge and I had much discussed, viz., the source of the E.M.F. of the voltaic cell. Soon, however, we had to separate. He went to University College, Gower Street, to study under Carey Foster and Henrici, whilst I went as science master to Cheltenham College and later on to Cambridge to study under Clerk Maxwell. Before long Lodge passed from the rank of student to that of teacher, and in 1881 was appointed Professor of Physics in the University of Liverpool. He rapidly increased his reputation as an investigator. The study of lightning discharges and of the discharge of a Leyden jar led him to researches on the propagation of electric waves along wires, and he came very near to anticipating Hertz's work on the production of Maxwell's electromagnetic waves in space. Hertz published his work in 1887 and 1889, and Lodge followed him by repeating and extending his experiments on the quasi-optical effects of electric radiation.

In June 1894, after the death of Hertz, Lodge gave a lecture at the Royal Institution on the work of Hertz. In this lecture he made use of a tube loosely filled with metallic filings, which he named a coherer, to detect electric waves.

I well recall that one day coming out of the Royal Institution he said to me "I have a new detector of electric waves." I said, "Would it detect an electric spark happening at the top of Bond Street?" He said he thought it would. Lodge repeated his lecture in the same year at Oxford at a meeting of the B.A. He then had a Hertz oscillator in a distant room, and by means of his coherer and tapper he made long or short deflections of the needle of a mirror galvanometer. He could thus have transmitted alphabetic signals, and in fact used all the arrangements for a wireless telegraph which Marconi later on improved and employed. Lodge had, however, more interest in theoretical physics than in creating practical applications. He had a firm belief in the actuality of an ether of space, and made many experiments, but not successful, to demonstrate its existence.

His unique powers of scientific exposition were well shown in his numerous published books on science. He had an excellent speech delivery and impressive manner and always held attention when he spoke at scientific meetings. In 1887 he was elected F.R.S. and in 1900 chosen for the post of Principal of the University of Birmingham, where he soon exerted, by his character and abilities, an important influence on the life of that city. Numerous scientific honours also fell to him and a well deserved knighthood in 1902.

My last interview with him was in 1937, when he came for a short visit to Sidmouth. But I was then sorry to see that his bodily strength was failing. His attractive and unassuming manner and charming interest in the work of others, as well as his own remarkable abilities and work, will secure for him an enduring remembrance in the minds of many friends and co-workers. AMBROSE FLEMING.

LODGE AS AN ADMINISTRATOR

My knowledge of Lodge as an administrator is derived from two sources—conversations with him, after I succeeded him as Principal of the University at Birmingham, and information obtained from those who worked with or under him during his Principalship (1900-1919)—supplemented by study of the records in official minutes, correspondence and communications on administrative matters, and his own annual reports.

It must be remembered that Lodge left Liverpool for Birmingham under special conditions. Joseph Chamberlain, the first Chancellor of the University, had selected him, because he rightly felt that the new university, created by Charter and Statute in 1900 out of the Mason College, must have as its head a man of recognized intellectual distinction and achievement. Lodge at that date had as a Professor at Liverpool already won for himself an acknowledged position as a physicist of the first quality and he was in the prime of his powers. He had no wish to be a full-time administrative Head of a University which had yet to be built up and brought into an efficient working organisation. His main interest was in the special sphere of his own scientific work. An arrangement was therefore made, without which he would not have left Liverpool, dividing the administrative work between himself and the Vice-Principal, who had been the

Principal of Mason College, providing Lodge with a special laboratory for his research work, and leaving him free from a great deal of routine administrative detail. Lodge adhered to this arrangement until he retired. He had never intended to be a full-time administrative officer, subordinating his own special studies to such opportunities as full-time administrative work allowed. Moreover, Lodge at Liverpool had not been particularly concerned with "administration". He had taken his part as a Professor in the general affairs of the University, but he had been primarily concerned with teaching and above all with the original investigations and research which had made his reputation as a physicist.

"Administration" is a vague and general term, covering two very different spheres—the framing of policy and the execution and supervision both of policy and the daily and efficient maintenance of the system and organs of university government. Lodge was not interested in, nor did he feel any particular aptitude for, the purely administrative side. Nor was he interested in "finance", in the ordinary sense. He once confessed to me that he never could understand an annual balance sheet of income and expenditure, except for the patent fact that the totals on the debit and credit side must somehow be the same, and he added that he did not know why this item or that was on this or the other side of the account, but presumed that insertion or omission was made so as to bring about the required identity of totals, with no small admiration for the skilled accountant who managed invariably to achieve this essential result. And he was painfully aware, like Micawber, that a surplus of "income", however small, meant "felicity", and an excess of "expenditure", however small, meant "misery".

Freed, as he was, by the special arrangement that had been made, Lodge as an administrator concerned himself mainly with "policy", leaving administrative machinery and detail to the officers concerned. And it was as an administrator in this sense that he left his mark on the University. For a specialist in science his range of vision was wide and imaginative. He had a genuine interest in humanist studies and in education as a sphere of general culture. He understood and supported the ideals and place of the Faculty of Arts in a properly constituted university, and he saw to it that the new university did not grow up as a superior school of pure and applied science, with the humanist studies as starved Cinderellas to "science". Above all, he grasped from the first that the University of Birmingham must be the university of the Midlands, the apex of the educational organisation of the seven counties, specified in the Charter of its incorporation; and that, to achieve this, the Principal must not only be the chief liaison officer between schools, colleges and the university proper, but a personal force inspiring and binding men and institutions into a unified whole. His own remarkable gifts as a lecturer and his impressive personality enabled him to be a real Apostle of the "University idea" throughout the Midlands, no less than in the city of Birmingham. In this way, Lodge (unconsciously, perhaps, rather than deliberately) laid down his interpretation of the main function of the Principal;

and he bequeathed this as a legacy to his successor. A whole-time and purely administrative officer might have done much better than Lodge on committees and so forth and in the handling of the university finances. Lodge's gifts and vision were given to a higher sphere of administration, in which he left an abiding impression of a great and simple personality, of high scientific distinction, and with a wide range of cultural interests. The new university in 1900 needed such a man, and it found him in Oliver Lodge. CHARLES GRANT ROBERTSON.

LODGE AND THE AETHER

Lodge was intensely interested in experiments which might throw light on the nature of the aether; and in 1893 he made a contribution of outstanding importance. For eighty years—from Arago and Fresnel to Lorentz and Larmor—it was an open question whether aether was convected by matter pushing its way through it, or whether it remained stagnant. In the eyes of the "plain experimentalist" the Michelson-Morley experiment (1887) had decided definitely in favour of convected aether. But Lodge answered experiment by experiment, showing that though perhaps the earth might carry the aether along with it, smaller masses did not. Using a pair of circular steel plates 3 feet in diameter and 1 inch apart, rotating at high speed, he tested whether the velocity of light in the space between the plates was greater for a circuit in the direction of the rotation than in the opposite direction, and obtained a negative result. In estimating the crucial importance of this experiment, it should be realised that the facile suggestion that there might be "slip" between convected aether inside the plates and stagnant aether between the plates, was irrelevant to the issue. The delicate test of astronomical aberration had made it clear that there was no aether-slip anywhere near the surface of the earth; and the kind of convection which the Michelson-Morley experiment was supposed to demonstrate applied to the aether up to a considerable distance from the moving body. Lodge had therefore very effectively stirred up the problem again on the experimental side, and paved the way for the later theorists.

In the foreword to his book 'My Philosophy' (1933) Lodge wrote: "The Ether of Space has been my life study, and I have constantly urged its claims to attention. I have lived through the time of Lord Kelvin with his mechanical models of an ether, down to a day when the universe by some physicists seems resolved into mathematics, and the idea of an ether is by them considered superfluous, if not contemptible." Those who studied physics forty years ago will recall his 'Modern Views of Electricity' (effectively a work on the aether) as perhaps the most inspiring book of the time. In later years the weight of authority—most unwisely—succeeded in banishing the term aether from physics; and this was a great obstacle to Lodge in his eager and open-minded efforts to grasp the meaning of the modern theories. He survived to a time when those who had condemned the aether as superfluous were obliged to restore it in the form of inapprehensible particles packing the "negative energy-levels".

A. S. EDDINGTON.

LODGE AND WIRELESS

The name of Oliver Lodge has a permanent place in wireless history, for Lodge contributed to the fundamentals as well as to the practice of wireless. Even before Hertz published his experimental demonstrations of the wave nature of electric disturbances in space, Lodge was pressing to the same end through a study of electric nodes and loops on wires. As soon as Hertz's results were made known Lodge acknowledged his lead and enthusiastically repeated his experiments.

In the year 1889 Lodge noticed that two almost touching metal knobs in a circuit near a Hertzian transmitter tended to stick together whenever the transmitter sparked. On testing with a battery and galvanometer he found that a current passed, and by refining on this observation as the transmitter was moved to greater distances he discovered that a light contact between metals, shunted by a battery and galvanometer, constituted a very sensitive receiving unit. He called the contact a coherer. About the same time Branly (in 1890) described how a tube of filings could be used to indicate the arrival of Hertzian waves. Lodge immediately recognized that Branly's tube and his own single-contact coherer depended on the same principle and dubbed the tube a filings coherer. Though a filings coherer is less sensitive than a single contact it is more suitable for working a relay and was used for a year or two in early practice.

Between 1891 and 1893 Lodge gave some thought to the telegraphic possibilities of the coherer and devised means of "tapping back", that is, restoring the resistance of the contact by mechanical vibration. One method was to use the current through the coherer to operate a trembler, but it is probable that this was devised earlier by Popoff. A broad summary of Lodge's work during this period was given in his discourse before the Royal Institution in June 1894. Here he showed that a well-marked beam of ultra-short waves could be produced by a spark-excited sphere contained in a copper cylinder with an open end—a method re-invented many years later—and described how a receiver close to such a transmitter must be enclosed in a chink-free metal box and have its external wires threaded through metal tubes. One piece of apparatus employed in the lecture consisted of a coherer, battery and galvanometer coil in a closed copper box, the galvanometer needle being outside, and the waves being collected by an antenna a few inches long protruding through a hole in the copper. In fact, much of the short-wave technique of thirty years later was set forth in this discourse. Using longer waves—perhaps a metre long—he demonstrated the receipt of signals from a Hertzian transmitter situated in a distant room and estimated that a range of half a mile was possible. Using still longer waves he showed his famous experiment of the syntonic Leyden jars, which foreshadowed directive wireless by loop antennae. A few months later, at the British Association meeting at Oxford, he sent Morse signals across a distance of several hundred yards.

It now seemed obvious that wireless signalling could be made practical by

enlarging the transmitter—the receiver was already simple and sensitive enough. Nikola Tesla in 1893 had proposed the use of a large elevated horizontal conducting area, connected to earth by a long vertical wire, at both sending and receiving ends. But Lodge's view was that a Hertz antenna, or a halved antenna like Tesla's, when used with a spark gap in series or a coherer in series (as was the practice in lecture rooms the world over), had too large a decrement. The sender produced a mere "splash in the ether" and the receiver itself was non-resonant. Hence wireless signalling was impractical with known apparatus; one sender would disturb all receivers. He found the remedy and based his well known selective wireless patent upon it.

This patent, No. 11575 of 1897, utilises the fact that the expression for the decrement of a Hertzian antenna includes the term C/L. The invention consists in reducing this term by connecting in series a coil of substantial inductance, and, if desired, reducing the capacitance. Consequential improvements are then possible which further reduce the decrement. Firstly, the spark gap could be removed from the antenna to a branch circuit of the coil, thus utilising the coil as a one-to-one transformer. Secondly, at the receiver the coherer was removed from the antenna to a branch circuit of the coil or to a secondary circuit. Spark and coherer had then little damping influence, the antennae themselves oscillated freely, and many transmitters could communicate simultaneously with their respective receivers without undue interference. Thus began the Spark Age of wireless, which was to endure more than twenty years.

In the same specification Lodge describes a practical form of single-contact coherer, consisting of a steel needle pressed adjustably against an aluminium surface by a light spring. When used with a battery and telegraph instrument it was "decohered" by a permanently running trembler. When used with a telephone receiver it could be adjusted to be self-decohering. This is probably the most sensitive receiver ever devised. It was the forerunner of the crystal detector and telephone combination long employed in commercial wireless everywhere.

The 1897 patent was followed by a number of others covering detailed improvements and shared with Alexander Muirhead. These are interesting to the historian as they yield early examples of the art of separating and utilizing direct current, audio-frequency current and radio-frequency current, in the same network. But none of these has the importance of the 1897 patent. Much later, in 1919, this patent was investigated in Court and declared valid, and Lodge received a worthy financial reward. The corresponding American patent was the subject of large commercial transactions in the United States after Lodge had assigned it to a London financier for the sum of one dollar.

Lodge retained a keen interest in wireless until recent years, and took every opportunity of discussing progress. In the nineteen twenties, when he had a flat in Westminster, I sometimes heard a gentle tap on my front door about midnight and on opening saw the imposing form of Sir Oliver in a tremendous

ulster and a cloth cap. "I was on the way home", he would say, "and saw your hall light burning." Then for an hour or two we would discuss super-heterodynes, regenerative reception, or the clipping of sidebands. He would grasp all these modern notions and jargons easily, even when approaching eighty years of age. He always preferred looking forward to looking backward and would rarely say a word about his own pioneer work. Such modesty was but one facet of a generous and lovable personality. W. ECCLES.

LODGE AND PSYCHICAL RESEARCH

No account of Sir Oliver Lodge's work could be complete without some appreciation of what, apart from Physics, was the dominant interest of his life. Sir Oliver joined the Society for Psychical Research in 1884, and in the year 1901 took his place between F. W. H. Myers and Sir William Barrett, F.R.S., in its long line of distinguished presidents. From the first his interest was almost equally divided between the physical and the mental types of alleged supernormal phenomena.

In 1884, in collaboration with a Liverpool business man, Mr. Malcolm Guthrie, he carried out some pioneer experiments in thought-transference, using common objects and drawings as material for transmission, the subjects being two ladies discovered by Mr. Guthrie. These experiments, which left something to be desired in the way of precautions for excluding sensory leakage, convinced Lodge of the reality of telepathy, and the account of them makes interesting reading even at this date.

Perhaps the most important piece of work which Lodge did for the Society was his investigation of Mrs. Piper, the celebrated American *clairvoyante*, on her visit to England in the year 1889. All Mrs. Piper's movements were supervised, and the most stringent precautions taken to ensure that she should not guess the identity of the persons introduced to her. In the end Lodge reached the same conclusion as had been reached by Professor William James, the famous American psychologist. Neither fortunate guessing, nor fishing for hints, nor fraud—whether deliberate or unconscious—could account for the mysterious knowledge concerning the affairs of her sitters and their deceased relatives which Mrs. Piper in her trance displayed. To explain her extraordinary feats it was necessary to postulate at least thought-transference from the living, and even this hypothesis had to be strained to the very limit in some cases.

Five years later Lodge was at the Ile Roubaud in the South of France with Richet the physiologist, F. W. Myers and others, investigating the medium Eusapia Palladino, who was alleged to produce the phenomenon of telekinesis or the mysterious movement of objects without contact and at a distance from her body. In the following year Eusapia was caught freeing one of her hands by a trick, but despite this exposure both Lodge and Richet remained convinced that they had witnessed genuine telekinesis in the Ile Roubaud. Lodge affirmed that movements of objects were observed at the very moment when he held

separately both of Eusapia's hands and was at the same time controlling both feet with his own. The subsequent investigation of the Naples committee, which included two conjurers, was favourable to Lodge's claims.

During the last Great War, Lodge won a great public audience by his book 'Raymond' in which he described attempts to get into communication with his youngest son, who had been killed in Flanders. At sittings held with the medium Mrs. Osborne Leonard, several incidents which suggested telepathy, if not actual survival of memory, were reported, but it was obviously difficult for Lodge to conceal his identity from all the various mediums whom he consulted. Besides referring to incidents in his early life that could be verified, 'Raymond' purported to describe the new world in which he found himself. These traveller's tales of life in the Beyond were ridiculed by many rationalists of Victorian persuasions, who found it patently absurd that discarnate humans should speak of trees and houses and rivers, of drinking whisky or consuming cigars. Mr. H. G. Wells in particular launched a most bitter attack on Lodge in one of his novels. This attack seems strange in view of the fact that ten years later Wells enthusiastically acclaimed Mr. J. W. Dunne's theory of Time. For, according to Mr. Dunne, the world we enter at death is the world in which we move every night in our dreams and is therefore a replica of the present world. But it speaks volumes for the honesty of Sir Oliver that he made no attempt to suppress this controversial material which so easily lent itself to cheap ridicule.

It is as a philosopher of psychical research rather than as an investigator that Lodge will be remembered. He favoured what is known as the instrument theory of the mind-body relation. The brain is the instrument by means of which the Psyche is able to manifest itself in the realm of matter. For Lodge, matter was a mere indicator which registered more fundamental action that was going on in the Ether of space—or in space-time to employ modern language. This space-time, and not matter, was the true habitat of life and mind. The soul used the brain as a musician uses an instrument. If the brain (i.e. the instrument) was damaged by disease or accident the mental music would be of a poorer quality, but the player would still retain his integrity behind the scenes. Lodge believed with Myers and Bergson that memory-images were not to be considered as mere brain traces but were psychical entities having an immaterial existence and surviving the destruction of the brain. The consciousness which manifested through the brain is only a minute fraction of the whole personality functioning permanently in space-time. The instrumental theory has its difficulties, but whether one accepted Lodge's views or not, one was bound to admire the crystal clarity and unfailing lucidity of his exposition.

To know Lodge even slightly was to gain a new conception of the moral dignity of Man. Of lofty and unimpeachable integrity and imbued with a noble sincerity of purpose, he credited others with an equal degree of honesty and good faith. Conversing with him, one felt that here was a man with a gift of serene contemplation which had set him free from all egotism and lifted him above the petty trials of existence.

Lodge was one who sought truth not only on the high road but also along strange bye-paths to knowledge. In 1916 he wrote : " If there be any group of scientific or historical or literary students who advocate what they think to be a sensible, but what I regard as a purblind, view of existence, based upon already systematised knowledge and on unfounded and restricting speculation as to probable boundaries and limitations of existence—if such students take their own horizon to be the measure of all things—the fact is to be deplored. Such workers, however admirable their industry and detailed achievements, represent a school of thought against the fruits of which the Allied Nations are in arms."

For this same freedom of thought and unrestricted enquiry we are fighting to-day.

S. G. SOAL.

ALFRED FOWLER

Professor Alfred Fowler died on the 24th June 1940 in his seventy-third year. The scientific world has hereby lost a born investigator whose work had a profound and lasting influence on the study of astrophysics and spectroscopy, and those of us who have had the great good fortune to work in his famous laboratory at South Kensington have lost an inspiring teacher and a very good friend. He leaves a widow, a daughter and a son.

Born on the 22nd March 1868 at a West Riding village, and moving in 1876 to Keighley with the family, in which he was the seventh son, Alfred Fowler received his early education first at local schools and then, with a local scholarship, at Keighley Grammar School. In 1882 he came to the Normal School (soon to become the Royal College) of Science, as a Devonshire exhibitioner for one year, and as a teacher-in-training for the next four years. Taking his Associateship of the College (Mechanics, first class) in 1885, he became computer and assistant to Mr. J. N. (later Sir Norman) Lockyer in the astronomical physics laboratory of the College and the nearby Solar Physics Observatory. Fowler was greatly inspired by Lockyer's extraordinary qualities as a teacher, investigator and organizer; Lockyer, quick to recognize the outstanding ability and enthusiasm of this very young teacher-in-training, enlisted his further services by securing his appointment in 1888 to the newly created demonstratorship of astrophysics.

In the numerous and fundamentally important spectroscopic researches carried out both at South Kensington and also in Lockyer's observatory at Westgate, Kent, Fowler took a very great part; how great was not then generally known, but later became very evident to Professor H. Dingle in the course of a study of Lockyer's papers for the preparation of a section of his biography. The eclipse observations in which Fowler took part during this period were those of 1893 (Senegal), 1896 (Norway), 1898 (India), and 1900 (Spain). The spectroscopic work of this period had as one of its main objects the empirical classification of spectra of celestial and terrestrial sources. An especially important example

was the observation of the changes in the line spectrum of a chosen chemical element as the effective temperature and energy of excitation were " stepped up " (as in flame, arc, spark, tube-discharge both uncondensed and with successively increased capacity in circuit), which led to the recognition of spectra designated by Lockyer as, e.g., Si I, Si II, Si III, Si IV, and ascribed by him to " molecular groupings in successive stages of simplification ". The last stage attainable by these means Lockyer called a " proto-element "; e.g. the *H* and *K* lines were ascribed to " proto-calcium ". Although this was far beyond the limits of speculation to which the chemists or physicists of the day were prepared to follow Lockyer, Fowler, with a full knowledge and appraisal of the experimental basis of the classification, agreed with him to some extent but assigned the spectral stages to " *the same element* in successive stages of simplification "—a view afterwards adopted by Lockyer. This, as we now know, is much nearer the truth, and needs but the replacement of the undefined " simplification " by the more precise " ionization " to describe this classification in terms of modern atomic theory; thus, to take the same examples, the theory has indicated Si, Si^{+}, Si^{++}, Si^{+++} as the emitters of the above-named spectra, and assigned the *H* and *K* lines to Ca^{+}.

In 1901 Lockyer retired from the Professorship of Astronomical Physics but retained the Directorship of the Solar Physics Observatory.* Fowler, now appointed Assistant Professor of Astrophysics, was left to continue the instructional work and spectroscopic research with an equipment that was extremely meagre in comparison with that of Lockyer's laboratory and observatory, where an annual Government grant for apparatus and maintenance had, of course, either to be spent before the 31st March or to be forfeited, and as that date approached Lockyer would send Mr. Fowler up to Hilger's to see what he could buy with the unspent balance.

A considerable part of Fowler's time was occupied by undergraduate teaching, to which he gave much thought and care, visiting the students, both in the laboratory classes in the afternoons and also in the observatory in the evenings, to talk over their problems and lend them a hand. Yet these years, until, say, the beginning of the war in 1914, must have been the most thrilling and enjoyable of Fowler's scientific career. His researches, which always bore the mark of his astronomical experience, became more and more particularly directed to laboratory spectroscopy, and were of fundamental importance for the development of modern astrophysics and for the theory of the spectra and structure of atoms and molecules. His laboratory, which was rehoused in 1907 in the new Physics-Chemistry building of the Imperial College,† grew in equipment and activity until it could

* The observatory remained at its old quarters amongst the South Kensington museums, studios, laboratories and huts until its transfer to Cambridge in 1912, whereupon Lockyer founded The Hill Observatory, Sidmouth, which now bears his name.

† The Imperial College of Science and Technology, founded in 1907, includes the Royal College of Science, the Royal School of Mines and the City and Guilds Engineering College (formerly known as the Central Technical College).

quite fairly be described as unique amongst instructional and research laboratories in this country. In 1912, not long after the completion of the first Eagle mounting of a 10-foot grating, the equipment was described by Fowler at a meeting of our Society (these *Proceedings*, **24**, 168 (1912)) and demonstrated to Fellows who visited the laboratory. About this time, too, there was a steadily increasing number of distinguished overseas visitors, amongst whom were H. Deslandres, T. Lyman, F. Paschen, E. C. Pickering, H. N. Russell, F. A. Saunders, Max Wolf and many others. It was not long before postgraduate students from every continent came in constant flow for periods of research, and the apparatus and instruments, though considerable and still increasing, were never more than sufficient for the growing requirements of the laboratory.

On the astrophysical side of Fowler's work in this period three notable examples are the very elegant matching of the absorption bands in stellar spectra of the *o*-Ceti class by the emission bands of titanium oxide (since proved to be TiO), the equally remarkable reproduction of the unknown bands in comet-tail spectra by new bands associated with Deslandres' " negative " bands in the discharge through CO at low pressure (both systems being afterwards definitely assigned to CO^+), and the identification of band lines emitted by the magnesium arc *in vacuo* or in hydrogen, which he correctly attributed to magnesium hydride (now known to be MgH), in the sunspot spectrum.

Fowler again visited Spain for the 1905 eclipse. In 1912 at South Kensington he obtained valuable information from visual observations of the bright-line spectrum at the cusp at a partial eclipse; the writer has a vivid recollection of the leisurely manner in which Professor Fowler carried out these observations and made his notes, and the almost boyish delight he displayed as he invited the writer occasionally to view in the Evershed solar spectroscope some particularly interesting feature of the spectrum. For the 1914 eclipse he set out with W. E. Curtis * for Kiev in the hope of making similar observations photographically with a 10-foot grating in the Eagle spectrograph, but they had got only as far as Riga when the war started and they had to return. The grating itself, the only item they were able to bring back, was set up in a temporary Abney mounting which did duty in the laboratory until the return of the rest of the apparatus in 1924.

In his work on line spectra in this period of " pre-Bohr " empiricism, Fowler developed sources for the emission of new line-series and higher members of already known series, with a view to the recognition and exact formulation of whole families of series, especially series of " enhanced lines ". Under this head comes Fowler's production, in a condensed discharge through helium containing a small remnant of hydrogen, of entirely new series of which some lines had been observed by Pickering in ζ-Puppis, in Wolf-Rayet stars and in nebulae, but only

* Curtis had succeeded H. Shaw as senior demonstrator in the laboratory, and is now Professor of Physics at King's College, Newcastle-upon-Tyne.

one had ever been produced in the laboratory.* On the basis of certain empirical relations (which, however, were only approximately fulfilled) between the Balmer and the Pickering lines, the latter and all Fowler's newly discovered series were at first ascribed erroneously to hydrogen.†

Bohr's first papers on the theory of the spectra of H and He^+, which appeared a few months afterwards, required that all the new lines should be assigned, not to four series of H, but to two series of He^+.‡ Though Fowler had not made the correct assignment in advance of the theory, he found some satisfaction afterwards in the fact that it was one of his own former pupils, E. J. Evans, § who first obtained the lines in helium of high purity and verified the theoretical assignment.

Of equal importance for the simultaneous development of Bohr's theory was Fowler's establishment of a whole family of doublet series of Mg^+ involving, like those of He^+, four times the Rydberg constant appropriate to series in the spectra of neutral atoms; this work he described in the 1914 Bakerian Lecture of the Royal Society.

Fowler's work on band spectra during this period was not confined to the astrophysical applications mentioned above, but included also fundamentally important investigations, carried out in collaboration with Professor the Hon. R. J. Strutt (now Lord Rayleigh), of the spectrum of active nitrogen and of spectra produced by its action on various elements and compounds. The simplifications and modifications shown by bands in this source, as compared with the same bands in hotter sources such as flames and arcs, constituted a great practical advantage for the measurement and analysis of band systems, to several of which the new method was soon afterwards applied || in Fowler's laboratory. With the development of the quantum theory of diatomic spectra, some ten to fifteen years later, the importance of Strutt and Fowler's investigations was emphasized and the many effects observed received explanation.

It is convenient to mention at this point, although it came some six or seven years later, a second investigation carried out by Fowler and Strutt, namely, the identification of the bands observed at the ultra-violet limit of the spectra of Sirius

* The very prominent line at 4686 A. in a condensed discharge in helium, first at the time of the 1898 eclipse in India, and later in the Solar Physics Observatory at South Kensington by C. P. Butler.

† Lockyer had previously assigned Pickering's lines to "proto-hydrogen."

‡ Sir William Tilden, then Professor of Chemistry in the Imperial College, maintained from the outset that helium, and not the small trace of hydrogen in Fowler's tubes, was the emitter. It afterwards turned out that the few lines that in low dispersion appeared to be strong Balmer H lines were in reality the closely neighbouring lines of He^+. Fowler's tubes, some of which are still in existence, were far better than he himself supposed. It was while assisting Professor Fowler in his observations that W. E. Curtis discovered, independently of Goldstein, the band spectrum of helium, assigned many years later to He_2.

§ Now Professor of Physics at the University College, Swansea.

|| By Fowler and H. Shaw, the senior demonstrator, who died in 1911, and later by the present writer.

and other stars and of the sun at low altitudes as absorption bands of ozone in the earth's atmosphere. This result at once furnished the real explanation of the termination of all celestial spectra at about 2950 A. and assumed a first place in subsequent meteorological discussions of the upper atmosphere.

Fowler was elected a Fellow of the Royal Society in 1910, and was appointed Professor of Astrophysics in the Imperial College in 1915. In 1923 he became one of the first Yarrow Research Professors of the Royal Society and, now relieved of teaching duties,* continued to direct the research of the spectroscopic laboratory of the Imperial College until his retirement in 1934. The three main lines of laboratory work already outlined were continued throughout the years 1914–34, but now, of course, with a firm theoretical basis.

The analysis of atomic spectra as it stood in 1922 is described in some detail in Fowler's *Report on Series in Line Spectra*, one of the Physical Society's special reports. The main object of his own investigations was the production and analysis of spectra of singly, doubly and trebly ionized atoms, especially the alkaline earths and light atoms such as C, N, O and Si. His work on the spectra of Si, Si^{+}, Si^{++} and Si^{+++} formed the subject of his second (1924) Bakerian Lecture. The spectra of heavier emitters were by no means neglected; indeed, M. A. Catalan, working on manganese in Fowler's laboratory, discovered groups of lines known as multiplets and so provided the key to the analysis of many spectra which had defied all previous attempts.

Fowler was the first to recognize Rydberg series of band systems (those of He_2 in Curtis's spectrograms); and the analysis of the rotational and vibrational structures of bands and band systems, some new and some that he had known as far back as the Lockyer days, were published by him jointly with several of his pupils. He also identified at least two other diatomic molecules (NH and OH) in sunspots.

After his retirement in 1934 he became Emeritus Professor of Astrophysics, a Fellow of the Imperial College and a member of the Governing Body.

Fowler's scientific and administrative activities outside the college were numerous and often arduous. Of the Royal Astronomical Society he was in turn secretary (1912–18), president (1919–21) and foreign secretary (1931–36). He was the first general secretary of the International Astronomical Union (1919–25), in the formation of which he took a prominent part, as he had done in the activities of its predecessor, the International Union for Co-operation in Solar Research. He was a member of the Council of the Royal Society (1920–22), of several of its committees, and of the Board of Visitors to the Royal Observatory, Greenwich. He was President of Section A of the British Association (1926) and of the Institute of Physics (1935–37). He also served on the Executive Committee of the National Physical Laboratory and the Advisory Council of the Department of Scientific and Industrial Research.

* The instructional work passed to Fowler's former pupil, Dr. Herbert Dingle, who became Assistant Professor of Astrophysics and, later, Professor of Natural Philosophy.

For his services to astrophysics, Fowler received the honorary degrees of D.Sc.(Bristol, Durham and Leeds) and Sc.D.(Cambridge), the Gold Medal of the Royal Astronomical Society and a Royal Medal, and was created C.B.E. in 1935. L'Academie des Sciences, Paris, awarded him the Valz Prize and elected him *Correspondant*. The National Academy of Sciences, Washington, awarded him the Henry Draper Gold Medal for Astrophysics and elected him a foreign associate; he also received the Bruce Gold Medal of the Astronomical Society of the Pacific.

Fifty-two years, a long span even in the life of a veteran, had elapsed between Fowler's entry into the old Normal School of Science and his retirement from active work in the Imperial College. At a memorable gathering in the college Union one evening in October 1934, old students and old friends met to mark their affection for the man and their regard for his work. The thoughts in the minds of all of us were most fittingly and beautifully expressed in a speech by Professor Dingle *—as may be judged from a further tribute † to Fowler's work and influence which immediately follows this outline of his career.

W. JEVONS.

ALFRED FOWLER was pre-eminent among a small group of workers who bridged the gap between two periods of spectroscopic astronomy—that in which it was less and that in which it was more than an empirical science. The contrast is exemplified by two methods of approach to the problem of " nebulium ", in both of which Fowler had some share. When he began his work, Lockyer, with whom he was associated for many years, was concerned with the evolution of stars from nebulae. He had already conceived the main ideas of his meteoritic hypothesis, according to which the raw material of all heavenly bodies consisted of meteorites whose gradual rise of temperature through collision accounted for the succession of spectra from those of the nebulae to those of the various types of star. To establish the hypothesis, miscellaneous meteorites were enclosed in glass tubes. The tubes were exhausted by a hand-pump and gradually heated by a coal-gas flame while an electric current was passed through the gas in them. The succession of spectra was taken to indicate the order of volatility of the constituents of the meteorites, and the history of the universe was written accordingly. The MgO band at λ 5007 appeared at a low temperature, and one of the green lines of nebulium was identified with its head, which would appear as a single line at low intensity. As a contrast to this excessive *naïveté* it is scarcely necessary to recall how, towards the end of Fowler's career, the problem of the nebulium lines was solved by rational deduction from observations in a region of the spectrum in which direct astronomical work is impossible. (Incidentally it may be remarked that Fowler's own contribution to the solution of this problem is perhaps

* Fortunately, Dingle's speech has been printed in the *Record of the Old Students' Association* (December, 1934). To this and to other of Dingle's writings, the present writer is indebted for many of the facts given above.

† Reprinted from *The Observatory* (October 1940) by kind permission of the Editors.

insufficiently appreciated. His letter to *Nature* immediately after Bowen's suggestion was published converted a brilliantly probable hypothesis into a virtual certainty.)

For the change in the status of astrophysics thus indicated, Fowler himself was in large measure responsible. Lockyer, of course, to some extent outgrew his early credulousness in these matters, but he was essentially a bold theorist and, as such, unqualified for the needs of the moment. Spectroscopic theory was bound to be mere speculation so long as a satisfactory conception of atomic structure was lacking, and without such theory the successful application of spectroscopy to astronomy was possible only by means of *ad hoc* experiments interpreted with complete absence of prejudice or predilection for particular results. For this work Fowler was admirably fitted. He was by nature a careful and accurate observer, gifted with strong commonsense and devoid of all aspiration to adapt his conclusions to the demands of a more comprehensive hypothesis. Above all he had a passion for spectra for their own sake, and the apparent instinct for correct interpretation which accompanies such a passion. The successful production, identification, and analysis of a spectrum was a complete satisfaction to him. Others could make what they would of the results ; for him the artist's joy in his creation, not the philosopher's in his understanding, and he looked on a well-developed spectrum, as Keats on a fine phrase, with the eye of a lover. Qualities such as these were the essential requirements of astronomy in Fowler's time, and he was there to meet the need.

His first great achievement—the identification of the bands in the spectra of the late-type stars—is typical of his astronomical work. For years he had been showing these bands to students in the observatory, but so little were they understood that it was a matter of dispute whether they were absorption bands degraded in one direction or emission bands degraded in the other. Fowler was for absorption, and was so *en rapport* with the bands that when one day he examined the arc spectrum of a titanium compound in the laboratory, he saw immediately that he had reproduced the stellar spectrum, although not only were the bands now seen in emission instead of absorption as in the stars, but also the dispersion was so much greater than stellar spectra would bear that none but the most experienced eye would have found a direct comparison possible at all. But the work was as yet only half done. To have reproduced the spectrum was one thing ; to identify it was another. (One of the writer's first operations in a spectroscopic laboratory was the photography of a carbon arc in vacuum. He obtained a spectrum which Fowler at once identified as that of ammonia !) A series of experiments was therefore undertaken, as a result of which Fowler could say with confidence that the spectrum originated in titanium oxide.

The accuracy of Fowler's identifications—the carbon monoxide bands in comet-tail spectra and magnesium hydride bands in sunspot spectra are further examples—is remarkable considering the difficulties of the purely empirical method. Only the most critical and painstaking investigator could have succeeded

in this period between the ages of spectroscopic innocence and sophistication. In the former age the bands characterizing the red stars would have been assigned at once to titanium chloride, the compound introduced into the arc. In these days we assign them to TiO. This presumably final identification was beyond Fowler, as the former was beneath him, for chemistry knew only TiO_2. Empirical spectroscopy is limited by chemical knowledge, and Lockyer's dissociation hypothesis, prophetic though it was in principle, shows the risks inherent in any attempt to transcend this limitation in practice. It is interesting to reflect that Fowler's one important error in identification—an error which he shared with everyone else—arose from an abandonment, in favour of semi-theoretical indications, of the principles which had previously guided him. The series of " cosmic hydrogen ", which he was the first to produce in the laboratory, was never obtained from a hydrogen vacuum-tube but always from a helium tube in which hydrogen occurred merely as an impurity. Only the imperfect agreement of the wave-lengths with a formula resembling that of the Balmer series suggested that the lines belonged to hydrogen.

Undoubtedly the most significant of Fowler's achievements was his recognition of the importance of " enhanced lines ". This belongs, however, more to general physics than to astronomy, though it is in astronomy that it has received perhaps its widest and most fruitful application. It is impossible here sharply to isolate the work of Fowler from that of Lockyer, but the fundamental difference between the two men comes clearly into view in their attitudes to the discovery. Fundamentally the fact was that when the exciting stimulus was intensified, some lines in the spectrum of an element were weakened, some were strengthened, and new lines appeared. In other words, the element behaved as though it had two spectra, one prominent under weak and the other under strong excitation. Lockyer immediately saw this in terms of atomic changes, and constructed his dissociation hypothesis accordingly. Fowler saw it essentially as a classification of *spectra*, and would not go beyond the verified fact. Both agreed, in face of almost universal opposition, in regarding the discovery as one of fundamental importance, and the event more than justified their faith; but while Lockyer's bold flight of imagination failed magnificiently, Fowler had nothing to withdraw. Standing on his own firmly established ground, he proceeded to build with caution and confidence, and what he built stands for all time. It is futile to attempt to draw a moral from this. Men work according to their nature, and there is one glory of the adventurous imagination, and another of the conscientious reason. The house which Fowler built was a mere ornament until it was inhabited by atomic theory, but atomic theory would have been homeless and destitute without it.

Of the other aspect of Fowler's astronomical activities—his eclipse work—it is unnecessary to say much. It called for nothing specially distinctive of his peculiar gifts, though it exhibited in a marked degree the general efficiency and thoroughness which characterized everything he did. The eclipse of 1898,

which in company with Lockyer he observed in India, produced the finest objective prism spectra obtained up to that time, though Fowler himself thought more highly of his work in Africa in 1893. He had set his heart on obtaining the first photograph of the flash spectrum, and was prevented from doing so only by an error on the part of the helper responsible for signalling the time. The photographs, though a fraction of a second too late for the best results, were nevertheless greatly in advance of anything that had preceded them. Visual observations of the bright-line spectrum at the cusp during the partial eclipse of 1912 inspired him with the desire to photograph the spectrum with a dispersion permitting the extreme accuracy of measurement at which he always aimed, and this to him was the chief eclipse problem of his later life. Two wars and adverse weather have conspired to prevent this from being attempted so far, and now he will never seen it done. Twenty-eight years between conception and realization is not much on the astronomical time scale, but it is all too long on the scale of human life.

From the moment when in 1885 he became Lockyer's assistant until his appointment to a Yarrow Professorship in 1923, teaching occupied Fowler's attention to at least an equal degree with research. It was essentially in personal contact that one obtained what he had to give, and those who were privileged to work in his laboratory owe him a debt which it is not easy to estimate. With large classes he was not at his best. His lectures were always well planned and conscientiously delivered, but undergraduates in general did not see him in the most favourable light. Two of the most distinguished of them—Sir Richard Gregory and Mr. H. G. Wells—were in a mild way his despair: " They would keep stopping work to discuss socialism ", he would say. Nothing will persuade us to divulge Wells's examination result in astrophysics, but Gregory appears to have learnt the secret of making the best of both worlds. It was a distinct relief to Fowler when it became possible for him to concentrate his attention on research and the supervision of post-graduate students.

Although in one sense the narrowest of specialists—to him an error of a hundredth of an angstrom was often a thing to brood on with more ardency than the death-day of empires—no one was more vividly aware of the importance and interest of fields of knowledge outside his own. Occasionally a student would be something of an ugly duckling, yet Fowler's interest in him would be no less, but rather more, than in those of pure spectroscopic race. He had the ability to discern talent in whatever form it appeared, and if it were of a kind which he could not directly develop he would see that it received the opportunity which he judged it needed. Nor did he lack his own interest in a wider world, though he never allowed it to rival his main preoccupation. He was a true " type of the wise who soar but never roam ". Sometimes, at the Royal Astronomical Society Club, after a meeting at which some specially exciting paper had been read concerning spiral nebulae or the evolution of the stars, he would discuss the question in his shrewd, commonsense way, pointing out perhaps the obvious thing that most others had lost sight of, and always seeing through the inessential to the

vital point. Then would come a pause, and after a while one would hear: "About that oxygen triplet; I've been thinking . . . ."

This is not the place to appraise what is often unjustly called the donkey work which he performed for astronomy. His labours both within and outside the various offices which he held in the Royal Astronomical Society (of which he was President in the centenary year) will never be known in their entirety, so many of them having been done by stealth. The International Astronomical Union, he was wont to say, was his creation. As its first General Secretary he was responsible for framing the Statutes and setting the Organization on its feet. But all this has become absorbed into the general organization of astronomy, and its individual origin is lost. Both in this and in the field of research, few men have seen so large a proportion of their work become a common possession of which not many remember the source. None of his discoveries bears eponymous evidence of its authorship, except occasionally the series of ionized helium which he was the first to observe. He was content that it should be so. His satisfaction came from the consciousness of work well and truly done, that would outlive his own name. Yet in the realm of spectroscopy, it may truly be said of him: "Si Monumentum Requiris, Circumspice", for there is little to be seen there that does not take a colouring from, or owe its existence to, his labours. The memory of the man will live in the hearts of those who knew him, and most of all of those whose careers were started under his guidance. HERBERT DINGLE.

WILLIAM HENRY MASSEY

THE death of Mr. William Massey, M.V.O., M.Inst.C.E., on 13 May 1940, at the age of 90 years, reminds us of the remarkable diversity in education, training, avocation and status of those who had the good fortune to find common ground of mutual accord in early fellowship of the Physical Society of London. In great measure, the progress of the Society is to be attributed to the place it has taken in the development of the higher ranges of theory, and in the encouragement of experiment, methods of demonstration and applications to design and construction of devices for the use of man. Supporting the advance, however, have been Fellows who on broad lines have sought to improve and strengthen the social ties between all engaged in scientific and technical pursuits. In addition to the unique character of his work as an engineer and the personal charm that endeared him to his friends, it is well to remember therefore the aid Massey gave towards intercourse between the professions.

He was born at La Seyne, near Toulon, in 1850, but he spent his boyhood in England and received his education at Leeds Grammar School. His father, who was a contractor for engineering plant, appears to have intended that his son should follow in his steps, for he apprenticed him to a millwright in Leeds. At the age of seventeen the sea attracted the youth and he proceeded to Odessa as third engineer in a ship of the Russian Navigation Company—a company of

which his father was then manager. The sea training proved valuable, as it gave young Massey sufficient experience to become one of the managers of John Penn and Sons, the steam-engine makers of Greenwich. According to an account of his career given in *The Times*, he was, in 1873, selected with W. Froude, H. M. Brunel, and Sir Philip Watts to take part in the trials of H.M.S. *Devastation*, the first sea-going battleship in the Royal Navy to depend solely on steam for propulsion. Two years later, he accepted an appointment in Germany to assist in the design of warship engines for their navy. Upon his return to England, a curious incident gave to his career an entirely new bent. The story, as he related it, was that the widowed Queen Victoria, who cherished every remembrance of the lamented Prince Consort, was disconsolate because a steam engine from which he had derived considerable pleasure and amusement at Windsor Castle would no longer work, and every engineer who attempted to repair it had failed. Her Majesty therefore began to despise engineers. When Admiral Sir W. Hewett, who had been in command of the *Devastation* during the famous trials, was visiting the Castle, the Queen laid before him her grievance, and the gallant sailor assured her that if the services of an engineer of his acquaintance could be requisitioned, the engine would be repaired and the royal prejudice against engineers would disappear. Massey, in 1878, was accordingly summoned to Windsor, and so well did he fulfil what was promised that the Queen caused him to be appointed at the Castle. For more than 40 years, during successive reigns, he held the post of Consulting Engineer, or in official terms " Mechanical and Electric Light Engineer ", in the Department of the Master of the Household, signified by the Board of Green Cloth.

His duties in the royal palaces left him with time for many other activities. He was concerned in the design of the first steam dredger for the Fen District, and he was employed upon engineering problems associated with colliery work. Additional scope for his energies was found in 1881, with the dawn of the electric-lighting industry. In December of that year he inaugurated what was perhaps the first " Association of Electrical Engineering Firms ". They began with a luncheon at the " Ship and Turtle ", with Admiral Sir E. Inglefield as Chairman. In 1882, Massey was manager of the company that first lighted the Crystal Palace with electricity. The marriage of the Duke of Albany in that year was made the occasion for introducing electric lighting into royal apartments at Windsor.

Of his published writings there are but few. His most noteworthy contribution was in 1884 when, at a meeting of the Society of Telegraphic Engineers and Electricians, he discussed experiments made in train lighting with Swan lamps on the Metropolitan District Railway. In social matters, however, he was at this period particularly active. His name is recorded among the original members of the committee, formed in 1883, of The Dynamicables—described as " a society of electricians whose object was dining and social intercourse ", but, in fact, one of the most potent organisations ever brought together for the reform of the relationship between technical advance and legislation—an organization that

included as members or as guests Moulton, Kapp, Ferranti, J. A. Fleming, Forbes, D. E. Hughes, Crookes, Preece, Webber, Latimer Clark, Fleeming Jenkin and William Thomson. Massey was elected a Member of the Institution of Civil Engineers in 1888. He joined the Physical Society in 1889 as a Life Member, but he contributed no papers to our *Proceedings*. He was created a Member of the Victorian Order in 1921. ROLLO APPLEYARD.

HENRY STROUD.

HENRY STROUD was born at Bristol on 7 August 1861. He began his education at Bristol Grammar School and in 1879 proceeded with an Entrance Scholarship to the University College in that city, when Silvanus Thompson was Professor of Physics and Principal. In June 1880 he was eighth in Honours at London Matriculation and was awarded the Gilchrist Scholarship tenable at Owens College, Manchester, where for two years he studied under Balfour Stewart and Henry Roscoe. While at Owens, he won the Heginbottom Scholarship for Physics and the Dalton Junior Mathematical Scholarship. In the Intermediate Science examination at London he headed the First Class Honours list and was awarded the Neil Arnott Exhibition and Medal. Winning all the available scholarships in Mathematics and Physics in his immediate neighbourhood, he went with them to St. John's College, Cambridge. Here he was elected to a Foundation Scholarship of £100 per annum. In the 1885 Mathematical Tripos he was bracketed (with the late Professor Jessop) eighth Wrangler and with a natural bent for Physics he took, in the following year, a First Class in Part II of the Natural Sciences Tripos. Meanwhile he had graduated B.Sc. at London in 1883, being at the top of the First Class lists in Physics and Chemistry and obtaining the University Scholarship. Immediately preceding his appointment at the College of Physical Science at Newcastle-upon-Tyne he graduated Doctor of Science in the University of London by examination, taking Electricity as his subject.

In the closing years of the nineteenth century the college, newly named Armstrong College (now King's College), was the pioneer of higher scientific education in the north-east. Both Garnett (the then Principal) and the youthful Professor Stroud were great advocates of popular scientific lectures and there are still many people who remember Stroud's experimentally illustrated lectures, given in towns and villages throughout the northern counties, on x rays, radium and wireless telegraphy, at a time when these subjects were in their infancy.

Within the University of Durham he took an active part in the development of the College. He was a strong committee man, and on the Council he had much to do with fostering the applications of physics and mathematics to the engineering activities of the Tyne, which at that time were advancing by leaps and bounds. At week-ends he found time to collaborate with the late Lord Armstrong at Rothbury in his experimental researches on "Electric Movements in Air and

Water". It was not, however, in research that he found most scope, and though he published little himself he was always keenly interested in research and did much to encourage it in his students, endowing college prizes to that end. In 1923 he and Mrs. Stroud endowed the "Henry Clifford Stroud Prize for Physics" in memory of their only son, Captain H. C. Stroud, who was killed in an air battle over London at midnight on 7 March 1918. Later, after the death of his wife, Dr. Stroud endowed in her memory the "Eva Mary Antoinette Stroud Prize" for postgraduate research in Physics.

Professor Stroud represented for a time the Board of Professors of Armstrong College on the Senate of the University of Durham, was Dean of the Faculty of Science from 1919–1921 and during the two years before his retirement was Vice-Principal of the College.

On the formation of the North-Eastern Centre of the Institution of Electrical Engineers in 1900, he became a full member and later, in 1909–10, he was chairman of the centre. He took a leading part in the formation of the Electrical Engineering Department of the College, transferring much valuable apparatus from his own department for this purpose, and for a time he directed the teaching. On his retirement after forty sessions in harness he was elected Professor Emeritus by a college grateful for his valuable services. Stroud died in peaceful seclusion at Gerrard's Cross on 3 September 1940. GEORGE W. TODD.

WILLIAM EDWARD SUMPNER

THE death of Dr. W. E. Sumpner on 8 May 1940 at Sutton Valence, Kent, in his 76th year, made another gap in the now thinning ranks of the original students of the City Guilds Colleges. He was at Cowper Steet before the opening of the Finsbury Technical College, and continued his studies at University College, London, taking his B.Sc. with first-class honours in Mathematics and Physics in 1885. In that year he entered the Central Technical College as a Clothworkers' Scholar, and was awarded the first Siemens Memorial Medal in 1886 and the diploma (A.C.G.I.) in 1887. He took his D.Sc. in 1891, and was lecturer in the Electrical Engineering Department of the C.T.C. from 1888 to 1893, after which he was appointed Head of the Electrical Engineering Department of the Battersea Polytechnic. In 1895 he was appointed Principal of the Municipal Technical School, Birmingham, later renamed the Birmingham Central Technical College, where he remained until his retirement in 1930. Under his administration the school prospered rapidly; new departments were opened, among which he took charge of the Electrical Engineering Department, and a scheme for a large new building was approved in 1913 but has, unfortunately, been continually postponed by the wars and financial stringency.

On the practical side Dr. Sumpner's chief contribution was his valuable set of alternating-current measuring instruments, which he described in a paper

read at the Institution of Electrical Engineers in 1908, for which an Original Communication Premium was awarded; but his writings covered a wide field, comprising over a score of papers on electrical measurements, A.C. theory and radiation, and illuminating engineering, contributed to the Royal Society, Physical Society, Institution of Electrical Engineers, *Philosophical Magazine*, British Association, &c., and he gave the Kelvin Lecture to the Institution of Electrical Engineers in 1932 on " The Work of Oliver Heaviside ".

He was awarded the Paris Exhibition Premium in 1888, the Fellowship of University College and of the City Guilds Institute in 1894, becoming a member of its Delegacy. He joined the Physical Society in 1887 and was a member of Council from 1910 to 1916 and Vice-President from 1916 to 1918; became Chairman of the Birmingham Section of the Institution of Electrical Engineers, and also President of a society entitled the R^3, which was founded by Professor Poynting. In 1901 he married Miss Lucy Weeks, who survives him, with their son and daughter. His genial unassuming character made him popular with all his associates. C. V. DRYSDALE.

PETER WILLIAM WILLANS

Peter William Willans, who had been a Fellow of the Society since 1922, died on June 28th last whilst engaged on work with the Royal Aircraft Establishment.

Mr. Willans achieved for himself a notable position in the world of wireless although it was not until after the last war that he took up the subject with any serious object in view. He was a son of a member of the well-known engineering firm of Willans and Robinson of Rugby and was born on 27 November 1892. He was educated at Rugby and Hertford College, Oxford, and left Oxford in 1914 to enter the army, serving with the Royal Garrison Artillery. This appears to have been his first engineering experience, and after the war (in January 1920) he went to the Marconiphone Department of the Marconi Company as an ex-officer trainee under the Government scheme.

Whilst with the Marconi Company he was concerned with research and development work, a very notable product with which he was chiefly concerned being the Marconiphone " Ideal " inter-valve transformer which was a landmark in the development of high-quality broadcast and telephony reception. Before the advent of this component the employment of intervalve transformers had been regarded as synonymous with serious distortion, and the far lower amplification afforded by resistance-capacity coupling was generally employed where high-quality reception was desired. Willans's name will always be associated with this progressive step in this country. Willans also produced a new type of high-frequency resistance whilst with the Marconi Company and he also had a good deal to do with the design of the V3 and other early Marconiphone broadcast receivers. In the course of his work Willans early realized the necessity of equipping himself with a knowledge of mathematics sufficient for his use in

the profession he had chosen. This he acquired through his own determination and thereafter his assistance on mathematical problems was constantly sought. He was by nature an analyst and this was particularly apparent when he applied himself to the discovery of some elusive fault in a broadcast receiver or other piece of apparatus. His facility in tracing the cause of the trouble was often an object lesson to those less systematic in their approach.

When Willans left the Marconi Company in 1924, it was to join the wireless branch of the Igranic Electric Company and here he devoted his attention to the development of the superheterodyne as a broadcast receiver, and in producing an instrument with neutralising applied to the intermediate frequency amplifier, he was probably the first to do so. This was before the introduction of the screen-grid valve.

In 1928 Willans joined the Columbia Graphophone Company and designed many of their broadcast receivers, which were outstandingly efficient in their day. With the amalgamation of H.M.V. and Columbia, Willans continued radio research with the new organisation under the director of research, Mr. Shoenberg.

Anxious for independence of action and freedom to work on those problems which interested him most, he gave up his appointment with Electric and Musical Industries in 1933 to undertake consulting work and to pursue those special lines of research. He made valuable contributions to the development of television and solved some important problems in broadcast studio acoustics in connection with which he developed a new type of " conduit " microphone enabling accurate measurements to be made with the minimum disturbance of the sound field.

It would be superfluous to enumerate the many other contributions which Willans has made to the development of radio communication because those we have mentioned are more than sufficient to show that he had been an outstanding engineer of the period of post-war development. Almost all the progressive steps which have been made touch upon his work and contributions at some point. To take one notable example, Willans many years ago proposed the use of L.F. correction to compensate for loss of high notes due to reaction. This effect was prominent in the discussions which took place when Dr. Robinson introduced his " Stenode Radiostat ". Willans's proposal might also be regarded as having some bearing upon the development of the principle of negative reaction.

In addition to his scientific abilities Willans was an accomplished pianist, and had his energies been fully devoted to music it is probable that he would have been equally eminent in that sphere.

All those who came in contact with him in the course of his work would pay tribute to his ability and few among them would not also regard him with affection. His death at so early a stage in his career is not only a loss to science but a personal loss also to those who have been associated with him and have valued his friendship. Willans leaves a widow and three young daughters.

H. S. POCOCK.

LOUIS OTTO MORITZ VON ROHR

Professor Moritz von Rohr, an Honorary Fellow of the Society, and well known in this country as an authority on Historical Optics, has recently died in Germany. No particulars are at present available.

He was born on the 4th April 1868 at Lazyn (Longlin) near the border town of Inowrazlaw (Kreis Hohensalza) in Posen, Germany. His prolific literary ability was inherited from an ancestor, Julius Bernard von Rohr, born in the family *Schloss* of Elsterwerda on the Saxony-Brandenburg border. Bernard, of necessity, his father having left many debts, became a Prebendary of the Chapter of Merseburg and devoted his inclination and energies to the writing, or rather compilation, of books, of which in ten years of his short life he produced over fifty, including a Dictionary of Domestic Economy and an imposing Dictionary of Physics. There was no subject in which he could not compile attractively.

Dr. Moritz von Rohr was a more specialized and more original writer, but equally remarkable for his great literary facility. Between the ages of twenty and twenty-four he was a student in Berlin. Immediately thereafter he obtained the degree of Ph.D. of Halle and a position as scientific assistant to the Royal Meteorological Institute, where he remained for three years until his appointment in 1895 to the technical staff of Messrs. Karl Ziess of Jena. While retaining association with the firm he assumed in 1913 the duties of Assistant to the Professor of Medical Optics in Jena University. From 1913 onwards he also undertook the editorship of the German Journal of Ophthalmic Optics, to which he made many contributions. His first scientific essay is dated 1895. It dealt with certain atmospheric phenomena observed during a severe thunderstorm in 1891, but it was only communicated after he had left the Meteorological Institute and entered the employment of Messrs. Zeiss, where the publication of such scientific work was encouraged. All his subsequent spare time was devoted to investigations in the field of Optics. which he found sufficiently extensive for the exercise of his literary enthusiasm. The harvest was plentiful. To enumerate his many works and contributions would not be possible. Probably the volumes best known in this country are his treatises on optical instruments published in 1918 and on binocular instruments in 1920.

After the war, in 1920, a translation of his comprehensive treatise on the formation of images in optical instruments was published by the Council for Scientific and Industrial Research. At the Optical Society in London in 1923 he delivered the Thomas Young Oration in excellent English, a language to which he was well accustomed, his wife being British.

As an historian he was indefatigable in deriving his information direct from the source. Thus Mr. H. R. Bow is well known to engineers who make general use of his Roof-Truss Stress diagrams and to the general public as the inventor of Bow's Liniment, but except to the specialist, his optical researches were unknown until their publication in the *Zeitschrift für Instrumentenkunde* of 1909 by

Dr. von Rohr after a brief sojourn in the Edinburgh home of Mr. Bow. He also brought to the notice of Continental readers the valuable Court Collection of Historical Instruments.

The writings of Moritz von Rohr, unlike those of his ancestor Julius Bernard, were spread over a period of forty-five busy years, not as a sole occupation, but supplementary to his professorial duties and his technical employment. His many treatises and contributions will long remain among the most valuable records of reliable historical information and research. JAMES WEIR FRENCH.

REVIEWS OF BOOKS

Geomagnetism, by S. CHAPMAN and J. BARTELS. In two volumes: Vol. I, *Geomagnetic and related phenomena*; Vol. II, *Analysis of the data, and physical theories*. Pp. xxviii + 1049, with 38 plates and numerous figures. (London: Oxford University Press, 1940.) Price 63*s*. net.

"Geomagnetism" is the term proposed by the authors for the earth's magnetism in preference to the more usual and more cumbrous term "terrestrial magnetism"; it is to be hoped that it will be generally adopted. Though a large number of permanent observatories are engaged on the measurement of the earth's magnetic field and its variations, though the subject of geomagnetism has an extensive literature (the authors of this treatise estimate that the main facts and results, which they have presented, are based on a hundred thousand pages of printed matter), though a monthly journal is devoted to it and though one of the constituent associations of the International Union for Geodesy and Geophysics is devoted to fostering and co-ordinating work in geomagnetism, there has been no modern comprehensive treatise on the subject. The most recent general exposition of geomagnetism in English, by E. Walker, was published in 1866, whilst Mascart's treatise was published in 1900; the scope of these works was limited, and since their publication the developments of the subject, both on the observational and the theoretical sides, have been extensive.

The need for a modern comprehensive ordered presentation of the facts and theories of geomagnetism has been great. This need has been admirably met by the work under review, which is likely to remain the standard work of reference on the subject for many years. The combination of authors is a particularly strong and happy one. Both authors have made many and important contributions to the subject; one has been primarily concerned with observations and their statistical analysis and discussion, the other with the physical interpretation of the observational data.

The treatise is subdivided into three parts. The first and longest part, comprising the whole of the first volume, deals with the observed facts of geomagnetism. The principles and methods of measurement and the instruments used both for absolute measures and for continuous records are described. It may be noted that plate 10 illustrates the La Cour ordinary recorder and not, as stated, the quick-run recorder. The main results of observation are then summarized in considerable detail; these include information about the earth's main magnetic field and its secular variation, and about the transient variations—the solar and lunar daily variations, and the storm-time and disturbance daily variations. Ancillary information about the solar and lunar motions and about the disturbances and other properties of the solar atmosphere, required for the proper appreciation or the analysis of the observational data, is given for the sake of completeness. The 27-day recurrence tendency in magnetic phenomena is fully discussed. Other topics dealt with in this part include magnetic prospecting, earth currents, the aurora polaris and the earth's atmosphere.

The second part is devoted to the methods and results of the analysis of the data provided by observation. It is prefaced by a valuable chapter on periodicities and harmonic analysis in geophysics. The useful conception is introduced of series of data with conservation, in which successive data are not distributed at random; in most

geophysical data, high values are likely to be followed by relatively high values and low values by relatively low values. The results of the analysis of the main field and of the principal variations are given separately.

The third part deals mainly with the physical theories that have been put forward to account for the facts as summarized in the first part and analysed in the second part. The authors admit that this is the part of the book with which they are least satisfied and which they feel will be the first to need revision. It is naturally the most speculative. Whilst the first two sections are invaluable for reference purposes, to theoretical and to practical magneticians, the third section will be found of the greatest use by theoretical investigators; it indicates to what extent theory has been able to account for the observational data and where further progress is needed. The origin of the main magnetic field of the earth and of its secular variation remains unsolved, but much progress has been made towards the understanding of the solar, lunar and storm variations. The section concludes with a historical chapter, summarizing the main facts in the history of geomagnetism. It may be mentioned that the vessel with which Halley made his magnetic observations at sea was not " the sloop *Paramour Pink* " but the pink (a narrow-sterned sailing vessel) *Paramour*. There is a fairly obvious misprint on p. 930, where it is stated that " at Greenwich Observatory the magnetic declination was read thrice daily . . . . from June 1818 to December 1920 ". For 1920 should be read 1820.

A valuable feature of the book is a detailed classified bibliography, extending to 70 pages. The literature of geomagnetism is scattered over a wide range of publications and this bibliography, though it makes no claim to completeness, will be of great assistance to all workers in the subject. Its compilation must have involved the authors in much labour. A series of tables greatly enhances the value of the work for reference purposes. These include a list of geomagnetic observatories, with geographical and geomagnetic co-ordinates ; annual means of geomagnetic elements at various observatories for selected dates; monthly mean magnetic-activity figures and sunspot-number data from 1872 to 1938; lists of international quiet and disturbed days from 1884 to 1937; daily relative sunspot numbers and international magnetic character-figures from 1890 to 1937. Such data are often required in geomagnetic investigations and it will be of great assistance to have them tabulated.

The work is completed by author and subject indices. Both of these have involved much labour and have special features. The author index gives references both to pages on which the author's name is quoted and to his papers listed in the bibliography. The subject index is planned to enable reference to any particular subject dealt with in the work to be readily made. It is divided into eleven sections, according to subject matter; the entries in each section are in alphabetical order, with the more important items subdivided and with cross-references. Indications are given if a figure or plate illustrates the item. Throughout the work, the chapter-sections, equations and figures are numbered separately in each chapter and the references to sections, equations and figures are in a form that enables them to be quickly found. The authors have, in fact, taken great pains to make the work as convenient as possible for reference purposes. The only adverse criticism is that each of the two volumes is thick and heavy, and consequently awkward to hold; a larger size page or thinner paper would have made them more convenient to handle.

The authors are to be congratulated on a work of outstanding achievement, which will be invaluable as a reference work and which will undoubtedly stimulate interest in geomagnetism and in its many problems that still await solution. H. SPENCER JONES.

Radio-Frequency Measurements by Bridge and Resonance Methods, by L. HARTSHORN, D.Sc. Pp. xiv+265. (London: Chapman and Hall, Ltd., 1940.) 21*s*.

This is a work that will undoubtedly take its position as a standard text-book on precise electrical measurements over the whole range of radio-frequencies from, say, ten thousand cycles per second to some hundreds of megacycles per second. It bears throughout the stamp of authority that can only come from an accomplished and experienced worker in this field.

The book is divided into three main parts, dealing respectively with Principles, Apparatus and Methods. Part I, the introductory exposition of underlying principles, consists of three chapters, the first being a discussion of impedance and related quantities; the second of the conditions for current and voltage resonance both in series and parallel circuits; the third of bridge methods, with special attention to screening requirements as regards both electric and magnetic fields. Part II is in five chapters, dealing, in the order named, with generators, detectors, and standards of capacitance, resistance and inductance. The question of the inevitable residuals or impurities in such standards is fully discussed. Part III, consisting of four chapters, deals with the actual experimental methods and details of procedure, the first and second chapters covering resonance methods, the third chapter bridge methods, and the fourth the special case of radio-frequencies so high that the dimensions of the measuring apparatus are no longer small compared with the related electromagnetic wave-lengths, when stationary waves have to be considered and radiation resistance may become appreciable.

It will be seen that the scope of the work embraces a searching treatment of both the theoretical and the practical aspects of the problems to be solved in order to attain definiteness and precision of measurement over the vast range of frequencies indicated. Nor are the quantities to be evaluated limited to the properties of apparatus such as resistors, condensers and inductors; they extend also to such properties of materials as dielectric constant, conductivity, and even (for frequencies at the top of the range) refractive index, involving the use of Fresnel's and similar formulae.

Such is the plan of the book. What of the execution ? Knowing the author's wide experience of electrical measurements at the National Physical Laboratory, and his many original contributions to the Proceedings of engineering and scientific societies, one's expectations are of the highest; nor are they in any respect disappointed. The theoretical treatment is concise and to the point. There is a wealth of information and of direction as to practical detail just at the places where one looks for it—the author seems to have thought of everything. The book is sprinkled with data of the greatest interest and value. And, what is of prime importance, the style of presentation of the subject-matter is admirable for its directness and clearness of expression. Every chapter is superlatively good, and there is a good index of subjects and authors. It is indeed difficult to discover any ground for valid criticism. It might perhaps have been well to point out that formulae (3) and (8) on p. 104 are only approximate. On p. 34 we have noticed a solitary misprint, where a symbol for vector voltage appears in ordinary type instead of the heavy type used to distinguish vector value from effective value. This method of denoting such pairs of quantities is in accordance with the recommendations of the International Electrotechnical Commission and the British Standards Institution, and the point is mentioned in this notice only to air the hope that some other distinguishing device may be adopted in order to escape the confusion that is so likely to occur between ordinary lettering and heavy lettering of the same form and size, particularly in handwriting.

Electrical measurements at high frequencies call for particular care and attention to detail if pitfalls are to be avoided. The use of this class of measurements is necessary not merely to the radio engineer but to many research workers in physics and physical chemistry. To all these, as well as to advanced electrical students, this book will prove a source of invaluable help. D. O.

Static and Dynamic Electricity, by WILLIAM R. SMYTHE. Pp. xviii + 560. (New York and London: McGraw-Hill Publishing Co., Ltd., 1939.) 40*s*. net.

In this new text-book on the subject of *Electricity and Magnetism*, the author has made a definite contribution to the literature of physics. He presents familiar subject-matter concisely and in an original manner and gives the modern theory of some branches of the subject, as in his account of the wave-mechanical treatment of magnetism. In the preface the author states that the book is written for the experimental research physicist and engineer rather than for the theoretical reader. But the presentation of the theory, if concise, is both sound and thorough, and all students of the subject are likely to profit by reference to a work which bears the mark of originality of thought upon the subject.

The chief feature of the work is its application to a wide range of practical problems. Many of these have recently assumed importance on account of modern technical applications.

An interesting characteristic is the replacement of the exploring magnetic pole by a current-carrying loop in the approach to the theory of electromagnetism.

The concept of vector potential is applied extensively, particularly in the derivation of coefficients of mutual and self-inductance. The treatment of this branch of the subject and also the chapter on eddy currents and skin effect are very useful additions, especially as few text-books deal with these questions.

It is assumed that the reader is familiar with the fundamentals of the calculus and with vector analysis, but the less familiar mathematical apparatus for the solution of problems is developed, e.g. the properties of Legendre coefficients and Bessel functions. There are of necessity certain omissions in what is usually regarded as the ordinary course in the study of electricity. But to include the whole range and to maintain the same standard throughout would make the book, consisting already of just over 550 pages, an unwieldy volume. This is a work to be recommended to all students of electromagnetism, especially to those requiring to make practical applications of the subject. H. T. F.

An Introduction to the Kinetic Theory of Gases, by Sir JAMES JEANS. Pp. 311. (Cambridge University Press, 1940.) 15*s*. net.

Sir James Jeans's new book can not only teach us much about the kinetic theory of gases but, what is even more valuable, something of the workings and development of a great intellect. Just as a comparison of Beethoven's *Choral Fantasia* with his *Ninth Symphony* shows how that composer's mind developed, just as a comparison between the earlier versions of some of Mozart's symphonies, written before the invention of the clarinet, with the revised versions in which that instrument was introduced will show us how an acute intelligence treated new possibilities, so a comparison between Sir James Jeans's *Kinetic Theory* and Dr. Jeans's *Dynamical Theory* shows the

direction in which the author's views have developed, and something of his attitude to the changes which have taken place in the 36 years which have elapsed since the publication of the earlier book.

This change is most notable in the direction of making things easier for the reader. The very title substitutes a trisyllabic adjective for the former tetrasyllable, and the book itself has become one which can be held in the hand when sitting by the fireside, whereas the earlier one demanded the respect of a chair drawn up to table or desk. Personally, I regret this particular change. The calm nobility of those beautifully printed blue-covered volumes which housed the thoughts, among others, of Lamb on *Hydrodynamics*, Whittaker on *Analytical Dynamics*, Jeans on *Electricity and Magnetism* and on *Dynamical Theory of Gases* has always made a special appeal to me.

But this is by the way. The book covers about the same range as the earlier one, but with much less mathematical detail, and in a different order. In many cases the wording is the same, or is only slightly altered, in the interests of still greater clarity. (This has led on p. 285 to a reference in the foot-note to a non-existent equation (403), which, as the reader will easily see, should be (383). Again, on p. 294 the reference to equations (399) and (400) should be deleted.)

The book differs markedly from the earlier one in making no reference to quantum theory. The account given in *Dynamical Theory* was of value in itself, as one of the earliest presentations of the theory in English, and, indeed, such an account was possible, at that stage of the theory, when it only involved the addition of quantum restrictions to classical equations. But quantum theory and classical theory now start from different bases, and it would appear less possible now than then to graft the quantum branch on to the classical stem. In any case, it would tax the ingenuity of the most skilled expositor to include present quantum theory, as it impinges on kinetic theory, without making heavy demands on the reader's mathematics.

If the book is compared, not with its ancestor, but with its contemporaries, we find that the outlook and terminology are closer to those of the old kinetic theory than to those of statistical mechanics, but that the ground covered and the results reached are roughly the same. The book is easier reading than several of the recent treatises have been, a feature which it shares with the summarizing chapters, addressed specially to non-mathematicians, in the earlier work. Such subjects as molecular aggregation and dissociation and the electron theory of metallic conduction still find their place, but there is little as to the motion of charged particles in a gas, and the reader has the impression that low-pressure phenomena, where the mean free-path is comparable with, or greater than, the dimensions of the vessel, have received little attention. But possibly this impression is erroneous ; it may be due in part to the fact that the results here are particularly simple, and so make less impression on the mind, and in part to the fact that the references to this subject are not collected in any one section but are scattered throughout the book.

It is certainly a book which no student can regret adding to his shelves, whatever else on this subject may be there, if only for the fact that it presents a picture of kinetic theory in which molecules and their movements, rather than points in phase space, occupy the foreground of the picture. The price is less than that of many recent books of similar size, and it is to be hoped that the sales will justify the publishers in this decision, and perhaps encourage them to try the policy in other cases. J. H. A.

From the National Gallery Laboratory, by IAN RAWLINS. Pp. viii + 50. (London: Trustees of the National Gallery, 1940.) 6*s*. net.

In this attractive volume we are given a glimpse of the fruits of five years' activity of the National Gallery Laboratory. Infra-red and X-ray photographs of famous pictures are reproduced side by side with "ordinary" renderings in fifty pages of unusual interest, and there are three pages of notes by Mr. Ian Rawlins.

As might be expected, the X-ray photographs reveal a great deal regarding the technique of the masters, and some of the steps in the final evolution of the completed pictures. Since white lead is used for the high lights in many compositions, the X-ray picture reproduced from the plate often bears a ghostly resemblance to the original, but on the other hand a dark background might owe much of its colour to lamp-black or some other substance which would be relatively transparent to X rays. Thus the X ray of Bellini's *Doge Leonardo Loreando* (reproduced on the dust-cover as well as inside) looks very much like a negative of the original. It is quite clear from the Notes that the interpretation of every picture affords a fascinating piece of detective work.

It is an excellent idea to give the kilo-volts and current used for each X-ray picture, but surely the value of a book of this kind would have been vastly enhanced by a few more pages of descriptive text. Thus we learn regarding Raphael's *St. Catherine*:—"Such a result with very soft radiation indicates a technique in which the substructure is a chalk (possibly containing a little iron) overlaid with very thin layers of colour." It is clear that the steps leading to such a conclusion must be of uncommon interest, and it is to be wished that Mr. Rawlins had felt able to describe them in outline at least.

There are a few photographs illustrating pigment structure, and perhaps the present writer may offer a suggestion in this connection. It is quite possible to make stereoscopic photographs in which the relief appears true to scale, using any degree of magnification. Would not this be a case in which stereoscopy might be used with considerable advantage?

May the days soon return when the National Gallery Laboratory will accompany its pictures back from their exile. L. C. M.

Physical Science in Art and Industry, by E. G. RICHARDSON. Pp. xi+293. (London: The English Universities Press, Ltd., 1940.) 15*s*. net.

To a reader with recollections of "The Fairyland of Science" and other such fascinating titles of earlier books on applied science in mind, the title of this latest book issuing from Dr. Richardson's fertile pen suggests by comparison something quite stern. If the title and contents of a book should epitomise the spirit of the age, Dr. Richardson fails in one respect: "The Art of War" is restricted, it is pleasing to note, to a mere dozen pages and is relegated to the concluding chapter. The seeker after deeper technical knowledge however will not be disappointed, and the book has been designed to provide the professional physicist with valuable technical information from widely scattered sources, collected together in a single volume.

The comprehensive nature of the field covered by the author is evident on a perusal of the chapter headings, and a brief survey of the book cannot fail to indicate the important rôle played by physics in the development of many varied arts and crafts. The problems of such contrasted subjects as Architecture and Locomotion, Farming and Mining, Textiles and Building Materials are reviewed; even cooking is not forgotten, and there

is a chapter on the Culinary Arts in which the mysteries of cream-making and egg-testing etc. are dealt with from the technical, but at the same time readable, aspect.

Non-creasable ties would not appear to be even remotely connected with air-raid shelters, but the solution of this neckwear problem should make possible the solving of a bigger present-day sartorial problem, namely the retention of creases in suitings only along certain desired directions.

The book is written in an easy and entertaining style; the reader is made to feel that Dr. Richardson is really interested in the subjects under his review, which is not surprising, as the author has carried out research work in many of these fields of investigation. Useful source bibliographies are provided at the ends of the chapters. Altogether it is a volume which should find a place on the bookshelf both of the professional scientist and the general reader. R. W. B. S.

Electrical Measurements and Measuring Instruments, by E. W. GOLDING. Pp. xii + 828. (London: Sir Isaac Pitman and Sons, Ltd., 1940.) 21*s*. net.

This is the third edition of what is described on the title-page as a textbook covering the syllabuses of the B.Sc. Engineering, City and Guilds (Final) and I.E.E. Examinations on the subject-matter of the shorter title. It is hardly necessary therefore to detail its contents. It provides the student with full particulars of methods of measurement and apparatus and, as a rule, of the underlying theory. Worked examples are given in illustration, and a selection of examination questions is included at the end of the book.

This edition contains some extensions bringing the subject up to date, and amongst these may be noted a section on the M.K.S. system of units. This system, by the way, seems likely to prove a rare puzzle to most students.

Generally speaking this work impresses as an adequate and competent presentation of its subject-matter, and should find the warm appreciation of the advanced college-student and of others interested in electrical measurements. A few criticisms may be of service. The first chapter consists of an introduction to electrostatic and electromagnetic theory, certainly not an easy task, and some revision appears desirable here and there. Thus on pp. 4 and 5 expressions for the electric intensity due to an element of charge on a sphere are incorrect ; on pp. 14 and 15 the same symbol H is used for two quantities of different dimensions ; and the last section, on the demagnetization curve (permanent magnet design), needs rather more exposition than the author gives of Evershed's mode of treatment. In the second chapter, on units, dimensions and standards, the derivation of $1/\sqrt{\mu K}$ as a velocity numerically equal to the ratio of the units of charge on the electromagnetic and electrostatic systems is not very convincing. Chapter III has the curious title " Symbolic Methods ", a wide term which is there limited to the usual treatment of alternating currents or voltages by the use of rotating vectors involving complex operators. This treatment, of course, calls for selection of a notation to distinguish vector value from effective value : the risk of confusion is not easy to avoid, and at several points in the chapter the symbols are misplaced. In a later chapter, in the derivation of the usual formula for the quadrant electrometer, the proof hinges on the statement that in a slight displacement of the needle the changes in the mechanical and electrical energies of the system are equal. But this is not obvious, and a little expansion is needed to make the truth acceptable, especially as these changes are, in fact, of the same sign.

The few suggestions here made are not intended to affect the view that the book deals very successfully, both as regards range and quality of treatment, with this important branch of the subject of electricity and magnetism. The physicist as well as the electrical engineer will find it a valuable addition to his library. D. O

University Physics (*Heat*, being Part 2 of a complete course), by F. C. CHAMPION. Pp. 148. (London and Glasgow: Blackie and Son, Ltd.) 5*s*. 6*d*.

It is stated that this book is intended primarily for students taking a First and Second year course in Physics at a University, and that it should cover the requirements for Part I of the Natural Sciences Tripos at Cambridge or the B.Sc. General Degree of London.

As a successful lecturer, Dr. Champion certainly knows better than the present reviewer what is demanded in these examinations, and he appears to have given the minimum that will suffice for this purpose. It follows that the student should know all that is to be found in the book if he wishes to be sure of passing. To some students this will be an attractive feature; others will prefer books which give more than enough. Those who do prefer to work from a minimum-requirements textbook will do well, though, to note the author's advice to "read widely and to acquire experience of the different methods of treatment of a subject . . ."

The book is divided into fourteen chapters, of which the first ten are descriptive of the phenomena usually classified as "Heat", and the last four deal with elementary kinetic theory, thermodynamics and radiation. The treatment in the first ten chapters is less full than in several recent textbooks, and it is noticeable that when illustrations of principles or methods are desired they are generally those sanctioned by tradition. Thus it comes about that no living worker from the National Physical Laboratory or the National Bureau of Standards is mentioned in the index, none from the Massachusetts Institute or the Munich High School, only two from London, Oxford or Cambridge Universities, and only two from the Reichsanstalt. Surely the interest of the subject would not be lessened, even for those who study it culturally rather than professionally, by drawing illustrations from modern work?

To prefer another method of treatment is not to say that there are errors of statement, and, in fact, there are very few, whilst the exposition, particularly in the final, theoretical, chapters is very clear. A few minor points for consideration in the next edition may be noted:—In discussing the merits of different types of thermometer, no mention is made of the possible errors when a mercury thermometer is used to measure falling temperatures; in convection no reference is made to the fact that a 5/4 power-law is the next approximation after Newton's law; modern work on thermal conductivity is ignored; the wet-and-dry bulb hygrometer described is of the unventilated type, and there is no reference to the superiority of the instrument in which a definite air stream passes the wet bulb; in Regnault's hygrometer appreciable errors can result if there is glass between the silver thimble and the cooling liquid, as seems to be suggested in the figure.

The book is excellently printed and the price quite moderate. J. H. A.

The Microscope, by R. M. Allen. Pp. viii+286. (London: Chapman and Hall, Ltd., 1940.) 18*s*. net.

In his preface to this book the author justifies its appearance by the statement that the number of books hitherto devoted to the microscope is small. He addresses himself to non-mathematical readers, and claims to base the book " on the best contributions of American and European manufacturers ". Originality is claimed in respect of methods and technique in mounting specimens.

In a final paragraph of the preface to this British edition of the book he explains that the failure to illustrate or describe a single British instrument is no reflection on English makers, whom he blames for making no effort to introduce their instruments into the United States.

The preface has been summarized because it gives an uncommonly good picture of the contents. The first two-thirds of the book consists of a mixture of elementary and inaccurate optics with material and pictures which appear to be taken from the latest catalogues of Zeiss, Leitz, and Bausch and Lamb. The remaining third deals with mounting technique ; this is dealt with clearly, although not in great detail. Even here, however, a lot of space is taken up by platitudinous remarks. For example, regarding the difficulty of getting alcohol :—" Institutions able to obtain it tax free and laboratories with permits to buy it are not troubled to the same extent."

The first chapter deals with the history of the microscope. The invention of achromatic lenses is ascribed to Euler ; and Lister's claim to fame is summarized thus : " . . . . Lister in England first joined the achromatizing doublets together with Canada balsam, thus increasing the effective light by almost one hundred per cent." The chance of finding accurate guidance on optical principles in the following chapters can be gauged very well by such a remark. It will be natural to turn to the treatment of " illumination ", and it is found to be explained in many words that " critical " illumination gives the best results, the method of securing this being to focus the image of the light-source in the plane of the object ; but after this we are told that critical lighting can be effected by an alternative method suggested by Köhler, in which the substage condenser is focused more nearly in the plane of the optical centre of the objective. The latter condition is neatly illustrated by a diagram in which light rays apparently pass undeviated through the lenses of the objective ! One gathers the impression that critical illumination (as ascribed to Abbe) represents a kind of Old Testament which can (on some occasions when desired) be superseded by Köhler with his new revelation. The novice may be pardoned if he experiences some confusion, and will not be comforted after having been assured that " a thorough appreciation of what is involved in the answer to this question usually revolutionizes the microscopical work of those who have previously assumed that sufficient (yet not too much) light is all that is required. Both the underlying theory of critical illumination and the practical means of securing it are easy of comprehension ".

Modern developments of microscopic methods, i.e. ultra-violet microscopy, the use of polarized light and fluorescence methods, are dismissed with little more than a mention. Nothing is said on electron microscopy. Photomicrography receives only about two paragraphs by reason that a complete discussion would take an " entire volume ". However, a number of the equipments shown in the plates include photomicrographic cameras.

The present writer does not review the work from the standpoint of a biologist, who will no doubt find it useful to be able to refer to a book in which modern apparatus is described in a general manner ; and although the treatment of the optical questions

is faulty it is not likely to lead a practical worker seriously astray. But there is so much that *does* require writing in regard to microscopy that it is a disappointment to find a text of this kind appearing, of which the only probable effect, if any, on the practice of microscopy (on the optical side) will be that the products of two or three particular manufacturers will sell more widely. Whether this is in accordance with the strict interests of microscopical science is a question which will suggest itself particularly to a British reader at the present time. L. C. M.

Properties of Ordinary Water Substance, by N. ERNEST DORSEY. Pp. xxiv + 673. (New York: The Reinhold Publishing Corporation; London: Chapman and Hall, Ltd., 1940.) 90*s*. net.

By arrangement with the Conference of Pure and Applied Chemistry which met in 1919, the American Chemical Society undertook the production and publication of scientific and technological monographs on chemical subjects, whilst they, with the National Research Council and the American Physical Society, undertook Critical Tables of Constants. This compilation of the properties of water in all its phases—water vapour, water and all the ices—is an outcome of this decision. It was begun under the auspices of a committee of the National Bureau of Standards, who remitted the work to the author. It is devoted to the properties of ordinary water substance, i.e. that of the usual isotopic composition, the summary of our knowledge of the properties of the isotope deuterium oxide published by Urey and Teal (1935) in the *Review of Modern Physics* making reference to this material superfluous.

The volume under review, containing nearly three hundred tables, is a most valuable addition to the reference library, and the author is to be congratulated on a fine piece of work. To the tables he has added a most helpful and lucid commentary.

The compiler commenced by assembling from the *International Critical Tables* all data pertaining to the properties of the ordinary water substance, but his revision and extension of this data in the light of more recent work, and the inclusion of data omitted from the Critical Tables, makes the work much more valuable and comprehensive. The term " data " has been interpreted broadly and includes much non-numerical information. Groups of interpolation formulae (e.g. for the thermal expansion of water) have been compared by means of skeleton tables. The author notes that this has revealed some persisting errors in recognized compilations and some oft-quoted formulae that are totally worthless.

As regards the scope of the volume, it appears to supply all the available information regarding the properties of pure, ordinary water substance in all its phases. It also deals with the phenomena and data pertaining to its synthesis and dissociation and to its transition from phase to phase.

Some out-of-the-way types of information are included. For example: the preparation of dust-free water and of monocrystals of ice, the colour of water and of the sea and the volumes of water menisci.

In the conclusion, the author heads a section *Surprises*, giving a list of a few of the things referring to water that seem to be thought-provoking. For example, the density of water that has stood in contact with carbon or with thoria is abnormal. Again, it was noted in 1868, and on two occasions since, that the refractive index of nominally identical water may vary. The author includes this without comment, and one wonders whether variation of isotopic constitution might be the explanation.

The index is full and thorough. E. G.

RECENT REPORTS AND CATALOGUES

Photographic Plates for Scientific Purposes. Pp. 7. KODAK LTD., 61–65 Kingsway, London, W.C. 2.

Price List of Laboratory Chemicals, Analytical Reagents, Stains and Solutions (1940). Pp. 96. W. & J. GEORGE, LTD., Proprietors of F. E. BECKER & Co., 17–29 Hatton Wall, London, E.C. 1.

Catalogue of Scientific, Medical and Miscellaneous Books and Periodicals. (Catalogue N.S. No. 37, 1940.) Pp. 35. WM. DAWSON & SONS, LTD. (Rare Book Dept.), Cannon House, Pilgrim Street, London, E.C. 4.

Foster Pyrometers, Tables of Constants. (F.L. 77.) Pp. 11. FOSTER INSTRUMENT CO., LTD., Letchworth, Herts.

The Hilger Photometric Colour Comparator (an Abridged Spectrophotometer), with a description of the *Hilger Photometric Amplifier.* (Hilger Publication SB 289, August 1940.) Pp. 8. ADAM HILGER, LTD., 98 St. Pancras Way, Camden Road, London, N.W. 1.

THE PHYSICAL SOCIETY

MEMBERSHIP

Membership of the Society is open to all who are interested in Physics:

FELLOWSHIP. A candidate for election to Fellowship must as a rule be recommended by three Fellows, to two of whom he is known personally. Fellows may attend all meetings of the Society, are entitled to receive Publications 1, 3, 4 and 5 below, and may obtain the other publications at much reduced rates.

STUDENT MEMBERSHIP. A candidate for election to Student Membership must be between 18 and 26 years of age and must be recommended from personal knowledge by a Fellow. Student Members may attend all meetings of the Society, are entitled to receive Publications 1, 3 and 4, and may obtain the other publications at much reduced rates.

PUBLICATIONS

1. *The Proceedings of the Physical Society*, published six times annually, contains original papers, lectures by specialists, reports of discussions and of demonstrations, and reviews.

2. *Reports on Progress in Physics*, published annually, is a comprehensive review by qualified physicists.

3. *The Catalogue of the Physical Society's Annual Exhibition of Scientific Instruments and Apparatus.* This exhibition is held normally in January of each year.

4. *The Agenda Paper*, issued fortnightly during the session, informs members of the programmes of future meetings and business of the Society generally.

5. *Physics Abstracts* (*Science Abstracts A*), published monthly in association with the Institution of Electrical Engineers, now covers practically the whole field of contemporary physical research.

6. *Electrical Engineering Abstracts* (*Science Abstracts B*), published monthly in association with the Institution of Electrical Engineers, covers in electrical engineering a field similar to that covered by *Science Abstracts A* in pure physics.

7. *Special Publications*, critical monographs and reports on special subjects prepared by experts or committees, are issued from time to time. Some of these special publications are :

REPORT ON THE TEACHING OF GEOMETRICAL OPTICS (1934). Price: 6*s*.

REPORT ON BAND SPECTRA OF DIATOMIC MOLECULES. By W. JEVONS, D.SC., PH.D. (1932). Price: in cloth, 20*s*. 6*d*.; in paper, 17*s*. 6*d*.

THE DECIMAL BIBLIOGRAPHICAL CLASSIFICATION OF THE INSTITUT INTERNATIONAL DE BIBLIOGRAPHIE (1926). By PROF. A. F. C. POLLARD. Price : in cloth, 3*s*. 9*d*.

MEETINGS

At approximately fortnightly intervals throughout each normal session, the Society holds meetings for the reading and discussion of papers, for experimental demonstrations and for special lectures, including the *Guthrie Lecture*, in memory of the founder of the Society, given annually by a physicist of international reputation, the *Thomas Young Oration*, given biennially on an optical subject, and the recently founded *Rutherford Memorial Lecture*. In addition, a Summer Meeting is generally held each year at a provincial centre, and meetings are arranged from time to time jointly with other learned Societies for the discussion of subjects of common interest.

SUBSCRIPTIONS

Fellows pay an Entrance Fee of £1. 1*s*. and an Annual Subscription of £2. 2*s*. Student Members pay only an Annual Subscription of 10*s*. 6*d*. No entrance fee is payable by a Student Member on transfer to Fellowship.

Further information may be obtained from the

ASSISTANT SECRETARY, THE PHYSICAL SOCIETY

1 LOWTHER GARDENS, EXHIBITION ROAD, LONDON, S.W.7

Moulders to the Trade *since 1899*

MOULDINGS IN BAKELITE, BEETLE, RESIN "M" and other SYNTHETICS

•

PLASTIC MOULDINGS in grades to resist Water, Acid, Heat, Alkali and Oil.

Mouldings in Bakelite and other synthetic resins, also in EBONESTOS plastic compositions, as used in the manufacture of electrical and other scientific instruments.

Since 1899 we have supplied many customers whom we are still serving satisfactorily. Such long continued business is the result of two things—the excellent QUALITY of our mouldings and our unfailing DELIVERY SERVICE. The services of our Technical Staff are available for advice on any matters relating to design, etc.

Let us know your requirements. Telephone, and one of our trained representatives will call to discuss with you any questions you may have regarding mouldings of any description or quantity—we can quote special mass-production prices.

EBONESTOS INDUSTRIES LIMITED

EXCELSIOR WORKS, ROLLINS STREET, LONDON, S.E. 15

Telephone: NEW CROSS 1913 (6 lines)

Moulders to the General Post Office, Admiralty, Air Ministry, and other Government Departments